MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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THE GEOLOGICAL SURVEY OF INDIA.

VOLUME XXI.

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CONTENTS.

ART. 3.—THE SOUTHERN COAL-FIELDS OF THE REWAH GÓNDWÁNA BASIN: UMARIA, KÓRÁR, JÓHILLA, SOHÁGPÚR, KÚRÁSIA, KORÉAGARH, JHILMILI, *by* THEODORE W. H. HUGHES, A.R.S.M., F.G.S., *Geological Survey of India.*

CHAPTER I.—GENERAL REMARKS.

CHAPTER II.—IDENTIFICATION AND DISTRIBUTION OF ROCKS.

CHAPTER III.—ECONOMIC.

CHAPTER IV.—APPENDIX.

ILLUSTRATIONS.

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MEMOIRS

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CONTENTS.

CHAPTER IX.

CHAPTER X.

Corrigendum in Memoirs, Vol. XX, Part 2.

The sentence at foot of page 53 and top of 54 was misprinted from Mr. Blanford's manuscript; it should be as follows :—

"In the hill ranges extending thence along the western side of the Indus the eocene system is poorly seen and appears to be entirely absent in places, as at Shekh Budin itself; where the system is represented it consists of limestone below, shales, clays, and sandstones above."

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

GEOLOGY OF THE LOWER NARBADÁ VALLEY BETWEEN NIMÁWAR AND KÁWANT, *by* P. N. BOSE, B. Sc. (Lond.), F.G.S., *Geological Survey of India.* (*With a plate and three maps.*)

CHAPTER I.

PRELIMINARY.

Literature.—The area comprised in this memoir has occupied me three working seasons (1880—83). It had been surveyed geologically by Messrs. W. T. Blanford and A. B. Wynne seventeen years ago. As no accurate topographical maps of the territory were available at the time, that survey was professedly preliminary. The work, however, was as satisfactory as could be expected under the circumstances, and has been reported on with consummate ability by Mr. Blanford.[1] This has, in one sense, been a disadvantage to me. On the other hand, Mr. Blanford's memoir has served me—a novice in field-work—as a mos trustworthy guide; and I have to acknowledge my indebtedness to it.

The literature of the district published previously to 1866, the date

[1] "Memoirs," Vol. VI, pt. 3.

of publication of Mr. Blanford's memoir, was noticed by him. Since that date the only additions to it have been,—

1869. Mr. F. R. Mallet's monograph on the Vindhyan series in the North-Western and Central Provinces, "Memoirs," Vol. VII, pt. 1. It covers the eastern portion of our ground from Hándiá to Barwâi, and deals, as the title of the work implies, chiefly with the Vindhyan system.

1875. Mr. H. B. Medlicott's paper on the "Shapur coal-field, with notice of coal-explorations in the Narbada region" ("Records," Vol. VIII, p. 65). Mr. Medlicott made out the unconformity of the cretaceous beds to the sandstone at Barwâi, which he considers to be Gondwana—an important result that will be referred to later on.

1879. A note on the "Joga [Jugá] neighbourhood and old mines on the Narbada," by G. J. Nicholls, C.S. ("Records," Vol. XII, p. 173).

Formations.—The following is a list of the formations, in descending order, described in the present memoir:—

Approximate European equivalents.	*Formations.*
UPPER CRETACEOUS . . .	(1) Deccan trap (igneous, mostly sub-aerial), with inter-trappean fresh-water limestone. (2) Lameta (lacustrine). (3) Coralline-limestone, (4) Deola and Chirakhan marl, (5) Nodular-limestone } (marine).
LOWER CRETACEOUS (NEOCOMIAN).	(6) Nimár sandstone (estuarine and fresh-water ?) with oyster band at the top.
JURASSIC	(7) Mahadeva (Upper Gondwana) sandstone (fresh-water).
	(8) Vindhyan sandstone (lacustrine ?).
	(9) Bijáwars, or transition series (marine).
	(10) Metamorphics (marine).

The formations (2) to (7) were described by Mr. Blanford under the general designation of "Bág" cretaceous rocks. At that time the Mahadevas were thought to be quite separate from the coal-measure series, and

to be closely connected with the Lameta beds. Mr. Blanford had not then seen either of these groups elsewhere, and he naturally suggested their correlation with the limestone and sandstone of Bág. Mr. Medlicott subsequently showed the Mahadevas to belong to the Gondwana system,[1] and afterwards identified the Barwái sandstone as Mahadeva on the grounds of similarity and the unconformability at Ghátiá.[2] With regard to the sandstones in the Bág and Rájpur—Chota Udepur regions, included under the title of "Nimár sandstone," the lower beds bear strong resemblance to the Barwái Mahadevas; but, unlike the latter, they pass above quite conformably into an oyster-bearing bed, which, on stratigraphical and palæontological grounds, must be affiliated with the cretaceous system. The typical area of this sandstone, lying to the west of the country now described, has not, however, yet been examined in detail, pending the publication of the new survey maps. As there is no prospect of these being published soon, the age of the Nimár sandstone must remain an open question for some time yet. If that age prove to be the same as that of the Mahadevas, *i. e.*, Upper Gondwanas, a highly important economic question suggests itself; namely, what chance there is of the occurrence of coal? As not a trace of the coal-bearing strata (Lower Gondwanas) has hitherto been found in the Barwái area, where there can be no doubt about the existence of the Upper Gondwanas, all that can be said at present is that the prospect is very remote.

In accordance with my instructions, the fossiliferous and the igneous rocks, the former specially, have been studied in greater detail than the older azoic formations. This accounts for the unequal distribution of space in the present memoir.

I have to express my obligations to Mr. H. B. Medlicott for numerous corrections and suggestions; to Mr. F. R. Mallet for his kind help in determining minerals about which I felt doubtful; and to Dr. O. Feistmantel, who guided me in identifying the fossils I collected from the cretaceous beds.

[1] Records, Vol. V, p. 115 (1872); Memoirs, Vol. X, p. 133 (1873).
[2] Records, Vol. VIII, p. 72 (1875).

CHAPTER II.

POLITICAL AND PHYSICAL GEOGRAPHY.

The whole of the valley north of the Narbadá, except the Chándgarh forest, the administration of which is in the hands of the Forest Department of British Nimár, is divided between Holkár, Sindhiá, the Rájá of Dhár, and the chiefs of Áli Rájpur and Chota Udepur. There are some petty states besides,—Dei, Nimkherá (or Tarla), Jobat, Máthwár, &c. Among the better known places, proceeding westward are,—Nimáwar,[1] Kathagaon, Ajnas, Kanod, Satwás, Kántáphor, Chándgarh,[2] Dhobgháttá, Kátkut, Barwái, Mandlesar, Mahesar, Gujri, Mándu, Nimkherá, Dharampuri, Chikaldá, Kuksi, Bág, Tándá, Jobat, Dei, Nánpur, Áli Rájpur, Káwant, and Chota Udepur.

South of the Narbadá, the British territory extends from Hándiá (Hindia) and Hardá to a few miles west of Mortakká. Lower down, the country is owned by Holkár, the Rájá of Dhár, the Barwáni state, and some petty states.

Except in the metamorphic country between Nimáwar and Satwás, and in the alluvial flat between Barwái and Chikaldá, presently to be mentioned, population is scant, and consists mainly of Bhils or tribes allied to the Bhils, such as the Kolis in the Chota Udepur state, the Kurkus of the Dhár forest, and the Bhilálás, all more or less pure aborigines, except the last, a portion of whom may be degraded Rajputs.

It has been found convenient to divide the whole into three areas, the maps being numbered from east to west. Each of these areas is marked by some geological and physiographical features, which it may be useful and instructive to summarise.

I.—Nimáwur—Barwái Area (Map No. 1).

The great Jabalpur-Hoshangabad alluvial plain terminates at Hán-

[1] A small village, being a collection of a few huts; but there is a police station, the only one in the district of Nimánpur, better known as the Dhár Forest.

[2] A small village, but important as the seat of a petty chief.

diá. The country thence to Chándgarh is moderately fertile and fairly populated on the metamorphic rocks; but the Bijáwars are comparatively sterile, and therefore covered with jungle. Between Chándgarh and Barwái, a barren, jungle-clad, hilly tract of sandstones and quartzites sparsely populated, and but little cultivated, intervenes. It comprises some well-known forests—the Chándgarh forest, the Dhár forest, and the Kátkut-Barwái forest north of the Narbadá, and the Punássá (Ponassa) reserved forest south of the river. The forests are co-extensive with the outcrops of the Vindhyans and the Bijáwars.

The Narbadá between Hándiá and Barwái illustrates in a most remarkable manner the close connection between physical features and geological formations. Broadly speaking, the river runs in a direction parallel with the strike of the metamorphics, *viz.*, E.N.E., W.S.W. Between Hándiá and Jugá (Joga) its course lies through variously hard metamorphic schists and granitoid rocks traversed by doleritic dykes; and the bed of the river (which is from ½ to over ¾ of a mile in breadth) is studded with numerous little islets of the harder rocks, making navigation impracticable. At Jugá the Bijáwars come in; these are comparatively harder, and lithologically much more uniform—siliceous limestones and breccias being almost the sole constituents; and the channel of the river is deeper, narrower, and less obstructed. Four miles south of Jugá, the Bijáwars come against the metamorphics; and a most remarkable change strikes the eye. The river becomes shallower and widens out suddenly to as much as 2 miles, with islands in its bed, the largest of which measures 1 mile in breadth and 2 miles in length. On entering the hard Vindhyan quartzites at Palási (Jamoti, a few miles below Chándgarh), it is again markedly narrowed and deepened, and flows through a gorge with magnificent wild scenery. A few rapids, and especially the fall at Dhari, interfere with navigation, but below that place water-carriage is practicable throughout the year as far down as Mahesar (map No. 2).

The Vindhyan range, the southern face of the Malwa plateau, takes, like the Narbadá, a direction parallel to the strike of the metamorphics.

Its average height above the sea-level in the area under consideration may be taken at 2,100 feet, and as the height of the valley above the same level is some 850 feet, a thickness of some 1,250 feet of basaltic rocks have been denuded away since the Deccan Trap times.

II.—Bág—Mahesar or Bág Area (Map No. 2).

West of Barwái (map No. 1) commences a tract of Deccan trap country, covered more or less by alluvium, with a mean height of 550 feet above the sea-level. It is continued into the present region, and extends nearly to its western extremity. The plain is widest between Dharampuri and Chikaldá, measuring 20 miles across. The soil, known as black soil, being very fertile, is well adapted for the growth of poppy, wheat, and other cereals. The country, in consequence, especially close to the Narbadá, is well populated, the largest and richest towns in the whole valley surveyed being situated on that river. Nearer the Vindhyan range the country is hilly, and poorer both as regards fertility and population.

Just below Mahesar, some falls interfere seriously with the navigation of the Narbadá. But between these falls (known as the Sahasradhara) and the Hurin Phal (13 miles west of Chikaldá), the river is navigable without much difficulty.

The Vindhyan range follows a north-westerly direction, corresponding with the change in the strike of the metamorphics in the area. It is elevated some 1,400 feet above the valley in the eastern portion of the country, as at Jám Ghât. But the elevation is gradually reduced, and the range loses in definition westward, north of Bág and Jobat.]

III.—Rájpur—Chota-Udepur Area (Map No. 3).

The Deccan trap country, which forms the southern portion of this area, is extremely hilly, the hills rising from 1,400 to 1,600 feet above the sea-level; and the Narbadá flows all the way through a deep gorge of basaltic rocks. South of the river the hills which have remarkably sharp outlines are spurs of the Sátpuras; and there can be no doubt

that those to the north forming the Máthwár and Káwant country were at one time continuous with these, but the connection has been broken by the denuding action of the Narbadá. The Vindhyan mountains which, as remarked before, lose in definition and elevation north of Bág and Jobat, get quite lost here among the older azoic rocks.

The metamorphic tract in the northern part of this area is comparatively less hilly, and proportionately more fertile. But, on the whole, the country is poor.

CHAPTER III.

METAMORPHICS.

The Nimáwar-Barwái (map No. 1) and Bág-Rájpur areas (maps Nos. 2 and 3) belong to two distinct regions of metamorphic rocks, and in describing the different formations it would be convenient to take them separately.

I.—Nimáwar-Barwái Area.

The prevalence of granitoid rocks is a marked characteristic of this area. The prevailing form is made up of large crystals of pink orthoclase, and smaller greenish-white, rather waxy-looking crystals, apparently of plagioclastic felspar,[1] and quartz, with chlorite and hornblende; another variety has the characteristic, large, orthoclastic felspar, and chlorite with a little quartz as its sole constituents. Both pass into well-foliated rocks; but the transition from the one to the other is nowhere seen. Besides the doleritic dykes probably of the Deccan trap age, to be mentioned hereafter, veins of trappean-looking rocks abundantly intersect the granitoid and schistose rocks. Some of these veins are of clearly segregative origin; as, for instance, a very hard, black, compact, fissile rock common about Punghát (Poonghat) and Fategarh. In other cases the origin is open to much doubt. In the district of Chándgarh,

[1] The felspar in question appears under the microscope as mere cloudy patches and does not show the colour-banding so characteristic of it in polarised light. I took it to be a decomposed form of the pink orthoclastic felspar, which shows beautifully fine cross striation with crossed Nicols.

near Pamákheri for instance, a hard, heavy, black doleritic-looking rock runs through the granitoid rocks in the form of dykes. Submitting it to microscopic examination, however, I found its composition quite different from that of the basic rock I took it to be. The blackness of the rock is due to numerous small crystals of greenish-black hornblende. These, along with small grains of quartz, are interspersed in a devitrified or altered microcrystalline matrix, which to all appearance is felspathic. The rock is probably a variety of quartz-syenite. It may be remarked that it has not in any way affected the surrounding rocks even at the junction.

The schists, of which quartz-schists are perhaps the commonest, almost invariably strike east with a little northing, and this constancy is a characteristic feature of the region.

II.—Bág-Rájpur Area (Maps Nos. 2 and 3).

Proceeding westward, the metamorphics are first met with as inliers in the Mán valley. Their main area, however, commences near Balwárá, whence it stretches away west, gradually widening towards Rájpur and Chota Udepur. East of Jobat in the valleys of the Uri and Wagni rivers, well-foliated gneiss and quartz and hornblende schists are most prominent; mica schist is rare; and so are granitoid rocks. North-west of Chirákhán, in the Mán valley, as well as at Mohanpura (near Ganwáni), and Báktála (near Balwárá), there are some insignificant outcrops of a hard, crystalline, siliceous limestone. It has considerable resemblance to the Bijáwar limestone; and during the first season I mapped it as such. Subsequently, however, I noticed an identical rock, which obtains very great development in the Hátni valley, about Jobat and Khattáli, associated with the metamorphics in such a manner as to leave no doubt that they formed an integral portion of the latter system. The limestone at places is highly crystalline, being made up almost exclusively of large crystals of calcite with well-developed cleavage planes. Its colour varies from black to white; being more durable than all the other members of the series except quartzite, it frequently forms ridges, though never of any great height. The rock is sometimes more or less foliated, mica being

found in the planes of foliation. In the northern portion of the Hátni valley, besides this limestone, there occur granitoid rocks and various kinds of schists; in the southern portion, however, as near Nánpur, gneiss prevails almost to the entire exclusion of these.

The metamorphic ground near Jobat demands a little more detailed notice, on account of its having been regarded differently by Mr. Blanford. At Begalgáon and Bilása, 2 or 3 miles east of Jobat, white quartzite abounds; proceeding westward, brownish, highly micaceous limestone and schists are found. Clay slates occur a few miles north-east of Jobat at Baira; but the slates cannot be traced far, and pass into talcose schists. All these rocks between Bilása and Baira form a somewhat elevated flat, between which and the Jobat scarp of a peculiar jaspery reddish rock the valley is occupied by a belt of a granitoid rock with quartz, orthoclase, black mica, and hornblende. This last-mentioned rock shows at places distinct foliated arrangement. It forms the base of the "red rock" scarp mentioned above, and is again met with at Jhiri and Ghungsiá west of the scarp. At Pángolá, in a depression formed by a streamlet cutting through it, there is found a granitoid rock somewhat different from the one just noticed. It is formed of flesh-coloured felspar, black hornblende, and specks and strings of a greenish mineral (epidote). Mr. Blanford noticed the presence of bronzite and serpentine besides.[1] Epidote is so abundant, especially towards the surface, that it obscures the felspar, and this affords a clue to the origin of the epidote, *viz.*, that it is formed by the alteration of the felspar. Under the microscope the transformation may be well studied. Serpentine is also an alteration product. Thus the original constituents of the rock would be reduced to orthoclase and hornblende; and it is probably a true syenite. In this connection, I may notice the occurrence of what appear to be baked shales in the immediate neighbourhood.

The whole of the ground just described from Baira to Jhiri, including Jobat, has been mapped by Mr. Blanford as Bijáwar. We shall find reason later on to assign to the "red rock" a much later date. Of the other rocks, the Baira slates are the only ones which have a Bijáwar

[1] *Op. cit.*, p. 156.

look about them. But they are so patchy and pass so insensibly into the metamorphics that they could not very well be separated from the latter. I noted the occurrence of similar slates associated with metamorphic limestone west of Jobat, as at Jowári, Páneri, &c. The gneiss of Ghungsiá and Undari would, from the proximity of the metamorphics, be more satisfactorily referred to these than to the Bijáwars.

South of Rájpur, north and east of the ancient town and fort of Ali, there is a hilly tract covered with thick jungle and cut into by deep ravines exposing immense thicknesses of granitoid rocks, the commonest member of which is similar to the granitoid gneiss near Jobat, containing orthoclase, quartz, mica, and hornblende. Here, however, there is some evidence of the rock being of intrusive origin. At Kánpur and several other places there lie masses of a dark-coloured, almost trappean-looking, nodular rock, with fragments of quartz, occasionally very large, which on microscopic examination turns out to be a trachytic rock. Orthoclase, quartz, and what appears to be magnetite, are disseminated through it in a devitrified matrix. The granitoid rocks pass into gneiss or schists in almost every direction except the south-western, where they abut against the Deccan trap as if by faulting.

Intrusive doleritic rocks occur throughout the whole of metamorphic area, all probably of the Deccan trap age. Some of these will be noticed hereafter.

The strike of the gneiss and schists, which latter are generally almost vertical, is remarkably constant, pointing north-north-west, thus differing from the strike of the metamorphics in the Chándgarh-Nimáwar basin, where quite as constantly it takes an east-north-east direction.

CHAPTER IV.

Bijáwars.

I.—Nimáwar-Barwái Area.

At Nimáwar, in the eastern extremity of this region, there is a quartzite ridge not more than a quarter of a mile in length, rising, as it were, out of

the metamorphics, and running in an east-west direction closely parallel with their strike. South of Hándiá (Hindia), another ridge of an identical rock, and running in the same direction for several miles, is very prominent. Similar ridges occur further west, and form the most characteristic feature in the scenery of the district, the white quartzite covered with low jungle being visible from long distances. The rock is of various degrees of compactness; but generally the quartz grains are readily distinguishable with the naked eye. The quartzites roll about a great deal. But the true dip is probably not very high. South of Hándiá the general inclination was found to be 5° to S-30°-E. But 8 miles to the south, north of Puchola, it is no less than 45° and directed northward. The chief quartzite ranges, as, for instance, the one to the south and west of Hándiá, mark the boundary between the Bijawurs and the metamorphics. But the boundary does not appear to be faulted, and the rock has no resemblance to the quartzites—hard, fine-grained, and compact—which we are accustomed to see along important fractures.[1] Indeed, at places it is so soft and unaltered, as at Chirákhán (Cheerakhan) between Jugá (Joga) and Hándiá, that it would be extremely difficult to distinguish it from some of the later sandstones. This difficulty is increased by its becoming at places highly conglomeratic.

The pseudo-quartzites (or rather sandstones) terminate westward at Jugá. Opposite this place in an island in the Narbadá, they are very well seen. They pass into brownish breccia to the west, which has the appearance of being faulted against the metamorphics. The dip is away from the fault 25° to 30° to the south.

On the authority of Mr. Mallet, Mr. Blanford has assigned the peculiar rocks just described to the transition series; and there can be but little doubt that that is the right place for them.

The other members of the series are limestone and breccia, both very characteristic rocks. The former is usually banded with chert or hornstone. The bands increase in thickness towards the surface; and

[1] The rock here suggested would be a vein-stone, and would be called quartz-rock, not quartzite; the latter term being usually restricted to metamorphic sandstone.—H. B. M.

masses of segregated silica are thus occasionally associated with the limestone. The laminæ are sometimes beautifully parallel, but generally still more beautifully wavy or concentric. This last-named structure, however, would appear to be confined to the uppermost beds. I found such to be the case in several pits. The chert-tubes are irregularly circular in section, with a nucleus of the same material in the centre. The collections of concentric tubes are not unlike the "geodes" in the Deccan trap, and, being certainly of similar origin, may be conveniently described under that name. Each geode is from 3 to 4 inches in diameter, and consists of 7 to 9 laminæ of chert alternating with limestone. When the bands are parallel they are inclined at all angles to the horizon; and the inclination may sometimes coincide with the dip of bedding; but, as it does not always do so, the former is a very unreliable guide. The true dip is best seen where the chert banding is absent, as near Barwâi, where the average inclination is 45° westward. At other places, as, for instance, near Jhirpániá, in the Dhár forest (Nimánpur), the bedding-dip (40°—55°, to N.-20°-W.) crosses the lamination dip at a high angle. But usually the former is quite obscured by the latter. If the bands cannot be trusted to represent bedding, it is equally doubtful if they "generally correspond to original cleavage planes," as they have been considered to do by Mr. Blanford; for the dips of the laminæ were found to be neither so generally high, nor, if high, so very steady as would justify such a conclusion. But that they may sometimes correspond to cleavage planes, as they may also to bedding planes, is evident.

The breccia, which is the other important constituent of the series, is a very massive rock, generally with but little trace of bedding. In colour it is characteristically yellowish or yellowish-brown. Along faults it is never missed, and, abutting against darker-coloured metamorphics, presents a beautiful contrast, and may be traced as far as the eye can see, if the fault-line happens to be in an open place, as, for instance, the bed of a large river, such as the Narbadá. The matrix is hornstone or jasper; and fragments of milk-white quartzite are dissemminated through it. Away from faults, the breccia alternates with the limestone, but there

did not appear to me any method in the succession. Iron ore (principally hæmatite) is abundant in, and appears to be confined to, the hornstone breccia.

Some vertical sandy shales and talcose schists, contorted at places, were met with cropping out from under the Bijáwar limestone in the Dhár forest, as near Jhirpániá. They are exactly like some schists which occur on the way from Barwái to Kotáwan (near Mándhátá), and which belong undoubtedly to the metamorphics. They are nearly vertical, and folded and crumpled at places, as just south of Jhirpániá on the road to Pipri. Their strike is the same as that of the metamorphics of the region. Their surface is very uneven; Bijáwar limestone with a dip nowhere exceeding 40° rests upon them unconformably. The unconformity is still better marked near Barwái. Near Billorá, between Mortukká and Mándhátá, the Bijáwar limestone, with a dip of about 50° to the west with a little southing, is seen to rest upon vertical or nearly vertical schists. The former has the appearance of being faulted against the latter; and the junction was taken to be a fault by Mr. Blanford.[1] But the fact that the schists, if traced to the north or south, are seen to pass irregularly under Bijáwar ground, seems to be against the idea.

If the peculiar sandstones or pseudo-quartzites at Nimáwar and Jugá be affiliated to the Bijáwars as they have been by high authorities, the case for unconformity becomes stronger; for they are not unoften surrounded by nearly vertical schists.

The dip of the series between Hándiá and Chándgarh is very unsteady in the rocks just mentioned, as has been pointed out before. In the limestone it generally points 20° or 25° south by a few degrees (10 to 20) to the east, in the jungle north of Pamakheri, in the district of Chándgarh, and near Balri (Buluria), 5 miles south-east of Chándgarh. In the Dhár forest, the dip was clearly seen in the limestone near Jhirpániá to be about 40° north-north-west, west of Mánsingpura some reddish fine-grained quartzites, with a remarkable resemblance to the Vindhyans, though stratigraphically an integral portion of the Bijáwars, are inclined 25°

[1] *Op. cit.*, p. 101.

south-south-east. In the Barwâi patch the dip is remarkably steady, being 45° to 50° west, or west with a little southing.

Throughout the area no cleaved rocks are met with in the series, unless we take the chert bands in the limestone when vertical to represent cleavage—a supposition which in this area does not seem to be very probable, considering that the verticality is far from persistent.

II.—Bág Area.

The Bijáwars in this area have been let down by faults. Besides the two faults discovered by Mr. Blanford, describing a triangular area on which the town of Bág is situated, I traced two others further east, which are also well marked. All the principal members of the series in the area have been fully described by Mr. Blanford, and need no repetition.[1]

The chert-banded limestone and the hornstone breccia of the Chánd-garh-Barwâi area are present; but the quartzite occurring between Hándiá and Jugá is missed. The most remarkable rock of the series, however, in the district—one which is entirely absent in the eastern basin—is a well-cleaved clay slate, quite good enough at places to be used for roofing purposes. It sometimes becomes conglomeratic by the presence of rolled pebbles of quartzite, which were observed to be drawn out in the direction of the cleavage. The strike of the slates is most remarkably parallel to that of the schists in the metamorphics, which again, as has been remarked already, is notably constant over very large areas. It may be concluded from this—first, that the foliation planes of the schists are planes of cleavages, not of bedding; and, secondly, that the disturbance causing this cleavage took place, at least in the Bág area, where the cleavage-strike of the Bijáwars is clearly parallel to the foliation-strike of the metamorphics, in post-Bijáwar times.[2]

[1] Memoirs, Vol. VI, pt. 3, pp. 35, 137, 140. A summary is given at pp. 45-46 of the "Manual."

[2] For a short discussion on this subject, see "Manual," pp. 31-32.

CHAPTER V.

THE VINDHYANS.

Area.—The Vindhyans extend as a low, wild, jungle-clad plateau cut into gorges and ravines, at places highly romantic, from the neighbourhood of Chándgarh to that of Barwái, a distance in a line of over 30 miles. An outlier, however, occurs south of Pungbát (12 miles east of Chándgarh), and is traced to near Sontalai, 8 miles further east.

Half-way between Mándhátá and Mortakká, close to the village of Billorá, there is exposed a splendid section exhibiting the lowest beds of the Vindhyans. These are seen to rest with well-marked unconformity upon some up-turned and denuded beds of metamorphic schists described before. For a mile south, and a couple of miles to the north, the same order of super-position is visible. Further north, however, the Vindhyans run parallel to the Bijáwars, as if thrown down against the latter by a fault, though the evidence for such dislocation is scant.

About a mile north of Árodá, on the Choral, they are covered up by traps. Five miles south-east, at Ranjna, they are faulted against the Bijáwars; and the fault is traceable for a distance of 20 miles to Bháuri-kherá, in the Dhár forest. The nature of the dislocation, however, is best seen at the deserted village of Andhári Bág, on the Kanár river, 7 miles east by south of Kátkut. Here the original fracture has been filled up by fragments of Bijáwar limestone and breccia cemented together into a singular agglomerate. For nearly half a mile down the river, the Vindhyan sandstones are very highly disturbed, the inclination being exceptionally high and variable, both as regards amount and direction. It is to be remarked that within this Vindhyan ground there was met with a band of breccia, exactly resembling the Bijáwar breccia. Its presence at first inclined me to include the sandstones just mentioned among the Bijáwars. But, on more careful examination of its stratigraphy, I came to the conclusion that it was an integral portion of the Vindhyan system. A repetition of similar features is observable in the Ghorápachár at Pipri, 4 miles to the east.

East and north of Bháurikhera the boundary line between the Vindhyans and Bijáwars is extremely irregular. The Vindhyans stretch away to Satwás and Chándgarh, where older formations are exposed at the base. All along the southern boundary the Deccan trap formation encroaches largely in the form of bays, and outliers of it are not uncommon.

The typical Vindhyans have not been known to extend further west than Billorá and Árodá (north of Barwái) in the Narbadá valley. However, 65 miles due west from the last-named place, in the neighbourhood of Balwári, as well as near Jobat, 25 miles further west, two patches of horizontally bedded, peculiar reddish-looking jaspery rocks traversed by a net-work of thin[1] veins of quartz occur, which, I am now inclined to think, probably represent the Vindhyans. At both the places they rest upon the metamorphics and pass under the Deccan trap, and are in close proximity to undoubted and unaltered sandstones and limestones belonging to the cretaceous system.

Jobat and Balwári beds.—Mr. Blanford maps the Balwári beds as "Bág" (cretaceous), though he does not express any decided opinion about their stratigraphical horizon.[2] As I could not make up my mind on the point during the first season (1880-81), I deferred colouring them until I had examined the vicinity of Jobat, where similar beds were supposed to exist. I examined this ground during the next season, and devoted to it more time, perhaps, than its importance demanded. The difficulty still remained unsolved. One thing, however, was clear. The cretaceous sandstones were distinctly seen to be unconformable to the "red rock;" so that it must be older. Mr. Blanford maps the Jobat patch as Bijáwar. But neither it nor any of the associated rocks has any striking resemblance to known Bijáwar rocks; whereas stratigraphically the contrast between the horizontality of the

[1] At Jobat grey limestones and conglomerates with a calcareous matrix and rounded lumps and nodules of quartz, as well as brownish, apparently baked shales, are associated with the "red rock."

[2] "Memoirs," Vol. VI, pt. 3, pp. 136, 153.

Jobat and Balwári strata and the high inclination of the transition series is very marked.

Unconformable to the metamorphics as well as to the cretaceous beds, the "red rock," which has puzzled me for two seasons, may, I think, be referred to the Vindhyans with more show of probability than to the Bijáwars. Mr. Blanford also remarks: "It is, of course, possible that this singular jaspideous rock, which is evidently nearly horizontal, may be newer than the Bijáwars."

Relations to older rocks, lithology, &c.—The relation of the Vindhyans to the older rocks is one of total unconformity. In the case of the metamorphics the Billorá section (between Mándhátá and Mortakká) shows this clearly. Several good sections showing unconformable superposition on the Bijáwars are also exposed, as near Jhirpániá in the Dhár forest, at Boriá and Mátni, south-west and west of Chándgarh respectively, near Pamákheri (a mile north-east of the village), &c.

The Vindhyans, like the Bijáwars, are too barren for cultivation, and the area occupied by them is approximately the area of the jungles of the district,—the Punássá reserved forest south of the Narbadá the Dhár forest, the Chándgarh forest and its northern continuation north of the river, being all situated on them.

The commonest constituent of the Vindhyans is a hard, compact, fine-grained, purplish, rather thin-bedded sandstone. White quartzites occur at places; they would appear to be due to local metamorphism. Conglomerates, occasionally extremely coarse, are not rare. Flag beds are by no means uncommon; and thinly stratified black or greenish-black shales were met with, especially towards the top of the system at Dhári in the Dhár forest. The sandstones and flags are generally micaceous, frequently very highly so.[1]

The Vindhyans in this area bear evidence of considerable disturbance. Commencing at the extreme eastern end of the superb section exposed on the Narbadá, from Palási (Jámoti, on map) to Billorá, we find them thrown into saddled-shaped folds, contorted and tilted up, nearly

[1] A peculiar-looking, thinly laminated sandstone, blotched with ferruginous concretions of the size of a pea, was met with near Sulgáon, between Barwái and Kátkut.

vertical at the first-mentioned village. This abnormally disturbed condition is noticeable for a mile only down the river. Thence to Semli (between Pemgarh and Dhári in the Dhár forest), the dip is on the whole steady and moderate, pointing in general to the south-west. Here an important synclinal axis is crossed, the beds beyond to the west of it dipping in a north-eastern direction. This dip continues to the western termination of the section with local variations both in amount and direction, due in most cases to doleritic intrusions.

Igneous intrusions.—The lower Narbadá Vindhyan area is, according to Mr. Mallet, "the only one yet known where the Vindhyans have undergone the intrusion of igneous matter."[1]

Of intrusions on a large scale, the dyke north of Dhári and Rámpura, in the Dhár forest, is the most conspicuous instance. It is elevated about 100 feet above the general level of the surrounding Vindhyan country, and is about 5 miles long. The hill (known as *Kaorabairi*) is made up of hexagonal or pentagonal columns of basalt, averaging 10 feet in length. The hexagonal shape prevails; one of the faces, however, is generally very short. At the extreme eastern end of the dyke-hill, the columns are perfectly horizontal, and lie with their longest diameter parallel to the direction in which the hill runs, *i. e.*, east and west. A few yards to the west, however, their length crosses this direction very nearly at right angles, and they are either horizontal or are inclined, though at a low angle, to the horizon, the inclination pointing northward. Horizontal arrangement of columns in the area under description is rare; I have observed only two more instances of it, to be mentioned later on. It establishes the intrusive character of the rock beyond a question; for the columns, according to the contraction theory, would be perpendicular to the walls of the fissure in which the rock cooled and consolidated.

The hill rises out of the Vindhyans, and beds of these are to be seen in contact with the dyke at several places. As far as I could examine, however, I did not notice any marks of exceptional disturbance or alteration in them, their dip preserving the usual north-eastern direction.

[1] "Memoirs," Vol. VII, p. 79.

Smaller intrusions are very abundant. They must be much more numerous than is indicated on the map. It is only where the super-incumbent beds have been removed by denudation that the dykes are exposed to observation; and of those that are observable not a few must lie hidden in inaccessible jungles. These small intrusions, passing through what may be called incipient fissures of eruption, have, unlike the larger ones, greatly affected the contiguous beds, as may be seen all along the Narbadá, from Palási (Jámoti) to Mándhátá. The dyke rock is a more or less crystalline dolerite, which shows that it solidified under greater pressure than that which produced the finer-grained basalt of the great dyke described in the preceding paragraph; and the greater resistance offered by the super-incumbent rocks in the former case probably account for their having suffered proportionately greater disturbance. This disturbance, however, is, as I shall have frequent occasion to remark in the course of this memoir, invariably local.

Age, thickness, &c.—The Vindhyans in this area are remarkable for being more uniform lithologically than in other parts. The lower series, composed mainly of limestone and shale, is entirely absent; and Mr. Mallet is apparently rather doubtful as to which of the three groups of the upper series (Bhánrer, Rewah, and Kaimur) the rocks here should be referred. He suggests the possibility of their including both the Rewahs and Kaimurs, though the two are no longer distinguishable.[1]

They form a shallow synclinal. A thick-bedded sandstone is never missed at the base. It is especially well seen on a hill (called Tengriá-páhár), a mile north-east of Jhirpániá, in the Dhár forest. Here massive beds of sandstone, each averaging some 8 feet in thickness, rest with marked unconformity upon the Bijáwars. As thickness of stratification has been noted as a characteristic feature of the Kaimur sandstone, the sandstone in question probably represents it. The higher beds may be referable to the Rewah group; and Mr. Mallet finds in the overlying shales "considerable, though not a strong, resemblance to those at Gunnoorgur, more to the eastward," and considers it possible that they

[1] "Memoirs," Vol. VII, pp. 55, 78, 98.

represent the lower Bhánrers (Bundair).[1] If such be the case, the covering sandstone must be upper Bhánrer.

It would thus appear that the several groups of the upper Vindhyans are represented in the lower Narbadá area. But as this is still problematical, they have been represented by one general colour.

The thickness of the Vindhyans in this area has been reckoned by Mr. Blanford at some 10,000 feet.[2] This estimate is certainly a very moderate one. Yet, as rippling is rather common, the deposits must have accumulated in shallow water.

The Vindhyans have nowhere yielded any fossils yet;[3] and in this absence nothing can be said with any certainty either about the age or the conditions of deposition. The balance of evidence, however, has been considered to be in favour of their fresh-water origin,[4] and as far as the lower Narbadá area is concerned, this hypothesis is strengthened by the total absence of limestones, and the prevalence of thin bedding.

CHAPTER VI.

GONDWANA SANDSTONE.

Distribution.—Some thick-bedded, rather soft, whitish sandstones are exposed by a streamlet at Agarwárá, 4 miles north-west of Barwái. They re-appear at Ghátiá, 4 miles to the east, forming a small scarp densely covered with an almost impenetrable underwood of shrubby leguminous plants. Further north, near Kátkut, fine-grained shaly beds, red, pink, or mottled with irregular ferruginous or carbonaceous concretions, averaging about 8 feet in thickness, are exposed by the streams and water-courses. At one place they were seen to rest upon a massive

1 "Memoirs," Vol. VII, p. 88.

2 "Memoirs," Vol. VI, pt. 3, p. 44.

3 With regard to the supposed fossils discovered by Franklin, Hardie, and Dangerfield, see "Memoirs," Vol. VII, pp. 102 and 103.

4 "Manual," p. xxiii.

bed of pink sandstone which may belong to the Vindhyan system. At Kátkut these beds pass into conglomerates and sandstones undistinguishable from the Ghátiá rock; and 2 miles east of the town they have been largely quarried from remote antiquity. The sandstones thin away to the north, being reduced to a conglomeratic band north of Chandupura, which is traceable with occasional increase of thickness by the superposition of a few feet of fine-grained rocks along the northern edge of the Dhár forest to Mánsingpura, 30 miles north-east of Barwái.

Two quite insignificant, hardly mapable, patches of sandstone occur at Rupabari, a mile south-east of Barwái. A similar rock is met with at Áhkund, 10 miles south-east of Mortukká. Here, too, the area covered is very small.

The base of the sandstones in this last instance was not visible. At Rupabari, Ghátiá, Kátkut, and throughout the Dhár forest, they rest upon either metamorphic or sub-metamorphic rocks. Their thickness is greatest at the Ghátiá and Kátkut quarries; and it does not exceed 80 feet. Everywhere the rock is horizontally bedded.

Relations to later rocks.—At Áhkund the sandstones are succeeded above with apparent conformity by calcareous beds, with fresh-water shells at the top having inter-trappean affinities. These beds are covered up by the Deccan trap. At Rupabari, inter-trappean limestones with the usual fresh-water fossils are met with in close proximity to the sandstones. But the stratigraphical relation between the two is obscure. The Kátkut and Dhár forest beds pass directly under the trap formation. Such is also the case north and west of Ghátiá. At the south-western corner of the upland, however, down in the valley of the Odali, an interesting intervention of fossiliferous beds occurs. These are quite insignificant in thickness and extent, measuring not more than 8 feet, and appearing as a mere speck on the map. Their existence was brought to light by Mr. Moore, the engineer in charge of the Ghátiá quarries, while the Narbadá viaduct, on the Indore State Railway, was under construction.[1] He discovered an oyster-bed a foot and a half thick, and

[1] Records, Vol. VII, pt. 3, p. 73.

traced it to within 400 feet of the Ghátiá scarp. The case is clearly one of unconformity, as pointed out by Mr. Medlicott. The circumstance that a short distance from the sandstone upland the transition (Bijáwar) rocks occur just below the oyster-bed, added to the undisturbed condition of the strata, disposes of the idea of a fault, as well as of a sharp curve in the bedding. The fact of the presence of a small patch of sandstone at Agarwárá exactly similar to the Ghátiá rock testifies to the former extension of the latter in that direction. It is clear, therefore, that it had suffered denudation before the deposition of the conglomeratic oyster-bed and the fossiliferous limestones. We shall in the two following chapters adduce grounds to place the one in the upper and the other in the lower series of the cretaceous system. The Ghátiá and Kátkut sandstone, therefore, being older, has probably to be located in the Gondwana (jurassic) system; and in that case there can be hardly any doubt that it represents the upper beds (the Mahadevas) of that great formation. This is the conclusion arrived at by Mr. Medlicott some years ago;[1] and my more detailed examination corroborates this view.

Fossils.—Several facts confirm this conclusion. The lithological resemblance of the sandstones under discussion to the Mahadeva rocks is striking, both consisting mainly of "coarse sandstone, grit, and conglomerate." The palæontological likeness is also remarkable. Fragments of drift-wood occur in the Ghátiá and Kátkut sandstone, and appear to be locally plentiful.[2] They are dicotyledonous; but nothing further is determinable with certainty: and these are all the evidence we possess of the life of the period. The Mahadevas of the eastern basin offer a parallel case,[3] yielding mainly fragments of hardly distinguishable exogenous wood.

Fresh-water origin.—The shallowness of the Kátkut basin is testified to by the conglomeratic character of the beds; and the presence of plant remains in such abundance east of Kátkut establishes the proximity of

[1] Records, Vol. VIII, pt. 3, p. 74. See also "Manual," p. 221.
[2] As at the Kákut quarries.
[3] A crocodilian scute and some leaves of Ptilophyllum have, however, been found in the Denwa and at Lokurtalai in allied beds. "Manual," p. 136.

land beyond question. The negative evidence of the entire absence of marine organisms may be less reliable as a rule. In this case, however, its value is increased by the fact that the closest search was made for fossils, but none beyond such as are indicated above have been obtained. It may be confidently asserted, therefore, that the Mahadevas of the western (lower Narbadá) basin, like those of the eastern, are of fresh-water origin. The deposit was probably formed in the delta of a river, which from the thinning out of the beds to the north-east must have brought sediment from that direction.

Absence of Lower Gondwanas.—Mr. Blanford finds resemblance in the fine-grained rock mentioned before as occurring near Kátkut to the finer sandstones of the Damuda series.[1] But the resemblance is not significant, and fine-grained sandstone is abundant in the Mahadevas, such as the Bágra stone, used in the Táwa viaduct. But the stratigraphy leaves no room to doubt that the rock is only a local variation of the Mahadevas: the basal beds of the series are seen to rest either upon the Bijáwars or the metamorphics throughout the area, from Ghátiá to Mánsingpura, in the Dhár forest; and the absence of a trace of the lower coál-bearing series of the Gondwana sytem is notable.

We thus get a decisive answer, though unfortunately in the negative, to the important economical question as to the occurrence of coal near Barwái.[2] What prospect there is of its discovery further west, we shall see in the next chapter.

CHAPTER VII.

LOWER CRETACEOUS SERIES : NIMÁR SANDSTONE.

Section I.—Area, Lithology, &c.

Near Barwái.—The rocks comprised in this series are first met with at Yálam (Yelam), 5 miles west of Barwái, below the fossiliferous lime-

[1] Memoirs, Vol. VI, pt. 3, p. 100.

[2] The answer is quite final for the actual outcrops, but the fact of a Gondwana basin remains. Mahadeva beds are known to overlap on metamorphics within very short distances of the coal-measures.—H. B. M.

stones to be described later on. The beds there seen are thin-bedded, fine-grained sandstones, which, as will be presently seen, belong to the uppermost portion of the series. Their relation to the sandstone described in the preceding chapter will be considered in the sequel in connection with the discussion about their age.

Between Chirákhán and Bág.—Between Yálam and Bowárla, some 50 miles to the west, no outcrops of aqueous rocks occur, except inter-trappean limestones of the Deccan trap formation. At Bowárla, fossiliferous limestones clearly of the same period as those of Yálam and Ghátiá are observed. Their base, not visible here, is exposed at Chirákhán, in a ravine a mile north of the village. Here between the limestones and the metamorphics intervene a few feet of coarse sandstones. These are much better seen a little further west, at the junction of the Mán with the Sukár. The thickness, which here does not exceed 15 feet, increases to the west; and south and south-west of Bág, as by the Wágni, it rises to 80 feet or more.

Proceeding up the Mán valley in a northern direction, the sandstones are lost sight of entirely; and the limestones repose directly upon the metamorphic schists.

The basal beds of the sandstone series are thick and invariably conglomeratic. The conglomerates, which are of all degrees of coarseness,[1] are succeeded by gritstones and sandstones, having variously coloured, thinly laminated, soft and friable, shaly and marly strata interbedded. The beds are frequently calcareous,[2] and often ferruginous.

The sandstones occur in the valleys of the streams which have cut through the upper cretaceous limestones. When the outcrop is of the conglomerate, pebbles from it, either weathering out on the surface or strewn in the fields by disintegration, form a characteristic feature. But if higher beds appear at the surface, they are usually coloured deep red

[1] Near Bág, as at Wágpura, Limkherá, &c., some of the pebbles, which are derived chiefly from the gneissose rocks, measure about 5 inches in diameter. Close to the junction of the Sukár with the Mán, south of Ghursul, small imperfectly rounded pebbles weather out beautifully in rows parallel to the planes of bedding.

[2] In specimens of hardened sandstone, small crystals of calcite are observed.

with oxide of iron; and fields of red or pinkish sandstone present a not unpleasant contrast to the black basalts and the white limestone.

The beds are, as a rule, horizontal. But a very low southerly dip was observed south of Bág,[1] and a much higher dip (15° to 20°) to the north by the Uri at Ajantár,[2] and a similar dip to the south at Ráherdá (on the Uri), as well as in the bed of a watercourse at Rámpura, between Billai and Khándlái, south of Bág. The disturbances in the Uri valley evidently took place in the interval between the deposition of the upper cretaceous limestones and the outpouring of the basaltic lavas of the Deccan trap period as they have affected the former, but not the latter. In the Wágni valley, on the other hand, the dip is the original inclination of bedding. Current bedding is especially characteristic of the shaly and marly strata, and is very well seen on the pillars and walls of the celebrated caves of Bág.

North-west of Bág.—West of Bág, as is also the case east of that town, the beds belonging to this series, when traced to the north, decrease in extent and thickness. A few inliers, probably nowhere more than 15 feet thick, were met with between Tándá and Bori. West of this latter town, hard, coarse, calcareous conglomerates occur at Kundalawása, of a somewhat different aspect from any found elsewhere. The variation, however, is merely local, and I have no hesitation in referring the rocks to the bottom beds of the Nimár sandstone. North-west of Jobat, at Umeri, Kiláno, &c., the sandstones, capped by Lameta cherts, with or without the intervention of the fossiliferous limestones, fringe the Vindhyan range to the south. They average between 40 to 50 feet, a thickness unusually great for them so far north.

South-west of Bág.—In this direction the sandstones are continued with one interruption to a few miles beyond Phulmal, the seat of a Thákur, in the state of Áli Rájpur. Between the villages of Walpur and Thorsindi, where the interruption occurs, the boundary is a fault, the con-

[1] It is clearly seen in the bed of the Wágni close to the town.

[2] North of this village, the sandstones are faulted against the cretaceous limestones.

tinuation of that referred to above,[1] which cuts off the granitoid rocks of Áli from the basalts of the Deccan trap system. In the stream west of Walpur, which marks the fault line, the strata are highly disturbed, dipping south and south-west at angles varying from 15 to 20 degrees, which I took to be evidence in favour of dislocation.

There is hardly any change in lithology, beyond that much of the sandstones by the Hátni is characteristically greyish or dove-coloured; and the succession of beds as exposed on the banks of that river is essentially a repetition of that seen on the Wágni, south of Bág. The only difference is, that there is an increase in thickness, especially of the fine-grained and shaly top beds. Ferruginous, reddish beds, similar to those noticed east of Bág, prevail about Rájáwat and Sejgáon (between Nánpur and Rájpur); and false bedding is noticeable everywhere.

At the villages just mentioned a low southern dip is observable, and about Delwáni and Háthwi a succession of insignificant dislocations occur by the Hátni river. The normal dip here averages 8°, to S.-15°-E. But opposite Háthwi (B.), where the river takes a southern bend, great variation is observed in it. Less than 200 yards east of the junction of a streamlet which flows through Delwáni and Chhota Háthwi, the inclination is suddenly changed to 15°, to N.E. This dip is preserved only for a few yards down the river, beyond which the beds incline southward with an intrusive sheet of basalt. It is about 3 feet thick. It is divided into rude columns nearly up to its termination, where it thins out into a greenish, soft, earthy rock, abutting against altered sandstones. A few yards further south the normal (southern) dip is restored and preserved until the sandstones, with the super-imposed members of the upper cretaceous series, are bent down and thrown against some basaltic beds highly inclined northward, which make up nearly 50 feet of the beautiful section exposed at the spot. The basalts with the covering sandstones are then bent southward forming a synclinal fold; and the usual dip is observed a few yards further down the river. Columnar below and scoriaceous above, they exhibit the usual structure of contem-

[1] See *ante*, p. 10.

poraneous flows. The beds in contact, however, both above and below, appear to have been altered, though not to any great extent; and the sudden and repeated variations of dip, and the local dislocations just mentioned, are best accounted for by regarding the basalts as intrusive, the point of intrusion being that towards which the strata on both sides are let down. The thinner sheet to the north of this point is certainly intrusive; and analogy would lead us to regard the southern apparently sister sheet as such also, though somewhat anomalous.[1]

It will be seen from this case (and several more will be noticed in the following pages) that the derangements caused by igneous intrusions are only local, though the underground forces of which they are the indications or precursors affect, as will be shown, very wide areas.

Passing down the Hátni over a mile of trap, we come upon an interesting inlier near Behron. Its northern boundary appears like a fault, the sandstones dipping away from the trap at 8° to 10°, to S.-10° to 15°-E. They thicken westward, and at the junction of the Walpur stream with the Hátni they are full 200 feet in thickness. Intrusive dolerites and basalts here intersect and tilt the beds in various directions and at various angles. At the eastern extremity the sandstones abut against a nearly straight dyke-like ridge of basalts, with huge masses of yellowish, altered, calcareo-siliceous rocks along its crest. Southward they terminate in low basaltic hills scattered all over with blocks of similar rocks, which will be noticed hereafter[2] more in detail.

The inliers of cretaceous rocks which dot the hilly district of Dei are most interesting in connection with the Deccan trap, and will be taken up in the chapter devoted to the latter. At Áli the sandstones come in with considerable and sudden increase in thickness. The faulted character of the eastern boundary has been referred to in a previous chapter in connection with the granitoid rocks which occur in the

[1] Mr. Blanford also considers the basaltic sheet in question as a horizontal dyke. The scoriaceous character of the upper basalt (which is the anomaly referred to in the text) may be accounted for by the thinness of the super-incumbent strata. This would argue in favour of their being regarded as of the Deccan and Malwa trap age, when a great thickness of infra-trappean beds would have been denuded away.

[2] See *infra*, p. 59.

district north and east of that now depopulated town. In the south, the cretaceous beds are cut off by an intrusion of basalt, and altered sedimentary rocks were met with along the boundary in this direction and for miles south of it. The beds in the northern and southern portions of the inlier, dip in opposite directions, best seen in the Ankhar river at Umrali and at Vegalgaon (B). It is probable, therefore, that Áli stands on an anticlinal axis. The beds here (including the highly fossiliferous nodular-limestone and the Lametas) cannot be less than 500 feet in thickness. The greater portion of this thickness is made up by massive conglomerates at the base. Fine-grained beds prevail, as usual, towards the top.

The Áli beds are continued westward as a narrow belt, and between Utaoli and Phulmal form a fringe to the metamorphics. The dips are in the usual south-east direction. They are rather high at places, as at Jharkali, where the inclination is 25°, to S.-20°-E. But this abnormality was clearly seen to be due to an intrusive dyke. The junction beds between the igneous and the sedimentary series are altered and tinted yellow or brown.

The Káwant area.—The inliers in this area appear all to have been brought up by violent subterraneous movements, and are so interesting that they deserve detailed notice. Leaving out an insignificant, unmapable patch covering only a few yards at Ráisingpura, there are 4 inliers, which I shall, for convenience of description, term severally the northern or Gáleser inlier, the middle or Mohan inlier, the southern or Mongra inlier, and the western or Tarkáchla inlier.

1. The middle inlier.—This is the largest. It rises as a ridge of sandstone from the Deccan trap beds, north of Rendi (the eastern extremity), and runs in a north-western direction for about 2½ miles. The ridge then curves southward, and pursuing a course roughly parallel with the strike for another 2½ miles, is lost amongst rises of sandstone cut through by numerous streamlets, exposing at places intrusive sheets and dykes to be noticed hereafter.

The sandstones are thickest about the ruins of Mohan, where they

rise to heights of some 300 feet, crowned here and there with patches of the upper cretaceous limestones and covered with thick jungle. They slope gradually south-eastward, in the direction of the dip, the higher beds and the limestones just mentioned appearing at lower levels.

The succession of beds is best seen along the Umti and Ráisingpura streams, which, uniting at Mohan, flow northward to join the Kara river, east of Káwant. The sequence in the descending order as exposed near Ráisingpura is—

UPPER CRETACEOUS.

(1) Deccan trap.
(2) Very hard, massive, coarse grits and conglomerates (Lametas).
(3) Purple concretionary marl. } Nodular limestone.
(4) Marly sandstone with oysters (especially at the base). } Nodular limestone.
(5) Marly limestone. } Nodular limestone.

LOWER CRETACEOUS (NEOCOMIAN).

(6) Thinly-bedded sandy shales with inter-stratified thicker beds, the former with trails of arthropods and worms and impressions of minute bivalves.
(7) Fine-grained white sandstone.
(8) Massive sandstones with yellowish specks, largely used as a building stone in the neighbourhood.
(9) Alternations of gritstones and sandstones.

Proceeding southward along the stream, the beds (2) are seen to be thrown down against strata belonging to the same horizon as (6), towards Chickli (B), and beds similar to (7) and (8) are found for a few yards, beyond which they are cut off by basaltic rocks.

Dips are well seen along the streams. They vary from 5° to 10°, to S.-10° or 20°-E., the higher dip being exhibited by the beds near the fault. Calculating from the average dip and the length of the section, the thickness of the beds exposed would amount to some 700 feet.

The north-eastern boundary line of the inlier up to Kákanpur is certainly a fault. The Deccan trap rocks to the north were observed to be inclined at places. At Nawalja the inclination was found to be exceptionally high (20° S.E.). But the usual dip is about the same as, if not less than, that of the sandstones, and is directed the same way. Low ridge-like rises of compact basalt, scarcely raised 20 feet above the

surface and capped by altered calcareous rocks to be noticed later on,[1] run parallel to the boundary line.

The northern boundary at Kákanpur, up to the streamlet which, originating a mile and a half south-west of Rájáwat, passes through Siriwasan to join the Gálesar-Kándibaro stream, is a curved continuation of the north-eastern fault. In a section south-west of Kákanpur the highest beds of the Nimár sandstone, with the overlying upper cretaceous strata belonging to the northern patch, presently to be described, are clearly seen to be faulted against lower beds of the same series with an unusually high dip (25°).

West of the Siriwasan streamlet mentioned in the preceding paragraph, the sandstones are cut off from the Deccan traps by a probably distinct fault. Their dips take a more southern direction and are higher (averaging about 15°), bringing the higher beds of the cretaceous system within a shorter distance of the boundary fault and at lower levels than is the case in the eastern portion of the inlier.

The fault at Ráisingpura has been already alluded to. It is traceable eastward as a crack; and in the Umti-Rendi stream the higher cretaceous beds are again seen to abut against lower ones of the system. The western portion of the boundary is extremely irregular, the sedimentary beds passing under stratified accumulations of volcanic ash and agglomerates, which will be described in the chapter devoted to the Deccan trap formation.

2. *Northern inlier.*—It is in shape like a bird, with its beak at Amalwat, body at Gálesar, and tail at Thargáon. The northern boundary looks very like a fault, and is parallel to that of the Mohan inlier. To the south, the boundary line from the western extremity at Thargaon to as far east as the village of Gálesar is remarkably straight.

Here the sandstones are cut off on the south by an intrusion of a hard, black, compact rock weathering light brown. Its matrix is microcrystalline, with innumerable little greenish microliths, most probably of hornblende; and dispersed in it are beautiful crystals of felspar; so that

[1] See *infra*, p. 59.

the rock appears to be a trachyte. A mile and a half south of Gálesar, an intrusion of the same rock similarly cuts off the sedimentary cretaceous beds of the Mohan patch. The dykes, especially the one just noticed, send off sheets in every direction. The trachyte is found in abundance westward, towards Ártiá and Tarkáchla; and, what is remarkable, between Bildá and Bákáner, among the unquestionably basic rocks of the Deccan trap age. These latter overlie the intermediate igneous rocks in such a manner as to place the greater antiquity of the latter beyond reasonable doubt. This affords a confirmation of the law regulating the chemical order of volcanic outbursts.

North-east of Gálesar there is an insignificant dyke of a basic rock, remarkable as the only one of the kind which takes a north-south direction. East and south-east there are ridges of trap, very likely erupted out of a small volcanic centre in the immediate neighbourhood, for associated with them are altered cretaceous rocks, especially towards the Kákanpur end. All along the northern boundary, most noticeably between Chápriá and Junwáriá (depopulated), there were found quantities of similarly altered rocks resting upon basalts, so often mentioned in the preceding pages.

The dips which are at places very well seen do not exceed 10°, and point in general to S.-20°-E.

3. *The southern inlier.*—This one, too, has been brought up by what look like faults, of which the northern one is closely parallel to those bounding the two preceding inliers in the same direction.

The lithology and mode of occurrence of some of the beds here require detailed notice. Just south-west of Chikli (B.) there is a ridge of a hard, white, compact calcareous rock, running in N.E.-S.W. direction, succeeded to the north by yellowish limestones, which from their fossils (*Bryozoa, Gasteropoda, Ammonites, &c.*) are referable to the nodular-limestone horizon. North and east they are covered up by the Deccan trap rocks; whereas westward they appear as if faulted against a ridge of sandstone elevated about 300 feet above the surface. Descending from this ridge at Mongra fossiliferous limestones similar to those at Chikli are met with, dipping at 10° to N.-20°-W.;

a few yards further west several small igneous intrusions are partially exposed; and in the stream, almost at the western extremity of the village, the uppermost beds of the Nimár sandstone (the thinly stratified sandy shales) are seen to lose themselves under the trap with an unusually high dip (30°) in the north-western direction.

4. The western or Tarkáchla inlier.—This inlier is the smallest. It has been brought up by faults roughly parallel to those which bound the sister inliers. Along the boundary faults, the non-basic igneous rocks described as occurring near Gálesar were met with, but in patches too fragmentary to be represented with any pretension to accuracy on such a small scale map as that which accompanies this memoir.

The faults spoken of above were evidently subsequent to the Deccan trap age; for the rocks belonging to the latter are seen to dip at several places, and in the same direction as the subjacent strata, and are faulted against the latter. At the same time, however, the movements which caused faulting could not have taken place long after those which preceded or accompanied the eruption during the Deccan trap times. The coincidence of the disturbed areas with those of volcanic eruption, as the Káwant and Dei areas will be shown to be in the following pages, would naturally lead one to infer some connection between the disturbing movements and the phenomena of eruption. Indeed, the remarkable parallelism of the fault lines with the dykes,[1] and the fact that in several cases dykes run along the faults, would thus appear to favour the conclusion that these were not far removed in age from each other.

Section II.—Palæontology and Age.

Drift-wood.—Fossils are rare. Fragments of drift-wood occur, like those obtained from the Gondwana sandstone, about Kátkut. Pieces of undeterminable bone were also found; and suspicious-looking casts (or rather what appear to be casts) abound at places in the shaly and marly strata.

At several places, and notably at Ráisingpura and Mongra, in the

[1] *Vide* p. 30.

district of Káwant, there occur in the soft, thinly-stratified shaly beds towards the top of the series well-preserved tracks of at least two kinds of animals. One of these resembles *Nereites cambrensis*[1] (a marine annelid), and the other is not unlike *Bifurculapes laqueatus* (an arthropod), from the Connecticut river sandstone.[2] These fossils have been sent to England for determination by competent authority.

Oyster-bed.—At Pipri-Ámlipura, 6 miles north-east of Bág, and nearly as many miles south of Tándá, close to the road which leads from Tándá to Dehri, I came upon an oyster-bed exactly similar to that described above as occurring at Ghátiá. About a foot in thickness, it rests quite conformably upon some horizontal, extremely coarse grit-stones of insignificant thickness (about 5 feet), and passes above, equally without break, into the lowest beds of the upper cretaceous limestone series (nodular limestone). The rock, like that of Ghátiá, is almost literally made up of layers of oysters from ½ inch to over 7 inches in length. Associated with the Lamellibranch were a Gasteropod, which I took to be *Natica*, and several pieces of undeterminable bone. Of the *Ostræa* there are at least two well-marked forms; but these may be varieties. The species is near, as far as I can make out, to *Ostræa leymerii*, an European neocomian form. Both at Ghátiá and Ámlipura the fossilised oyster-beds cover areas of quite inconsiderable extent.

At Ghátiá the oyster-bed passes under flesh-coloured limestones with Bryozoa and bivalves elsewhere met with in the nodular limestone, as well as with diminutive forms of the *Ostræa* just described in much diminished numbers. At Yálam, 4 miles to the west, a sandstone, with the same oysters sparsely distributed through it at the base of the limestone, probably represents the oyster-bed of Ghátiá. West of Bág, the oysters are met with at places (never in such abundance as at Ghátiá or Ámlipura) always at the top of the sandstone series; and south of Káwant they would appear to be rather numerous at Chikli (B) and Mongra.

[1] "Silurian system," pl. 27, fig. 1.

[2] "Ichnographs of the Connecticut river sandstone," p. 26, pl. 41, fig. 5.

The non-intervention of the oyster zone at places between the Nimár sandstone and the nodular limestone may be due to denudation of the former previous to the deposition of the latter; and, if so, the case would be one of slight unconformity. But the absence of the oysters may be due to local causes; and in this more probable case the beds in question would be considered to pass into the overlying limestones without any observable break. Nevertheless, the fact that the latter differ so remarkably from the former lithologically implies no inconsiderable lapse of time.

It may seem ridiculous to attempt to fix the age of a deposit, with any approach to precision, on the approximate identification of only one fossil, and that, too, merely an oyster. But this bivalve is a very characteristic fossil of the deposits under consideration; and if it passes up to the overlying limestone, as it does at Ghátiá and south of Káwant, it does so in considerably diminished numbers, and, as a rule, in diminutive forms, and dies out in the course of deposition. Now, the nodular limestone, which contains a well-defined marine fauna, will be shown in the next chapter to be on the same horizon as the gault or albian of the European cretaceous system. We may therefore ascribe the oyster-bearing beds, not without some show of probability, to a lower (neocomian) horizon. The oyster being closely allied to an European neocomian form adds strength to the supposition.

Age of Nimár sandstone.—With regard to the age of the sandstone underlying the oyster beds (the Nimár sandstone), it is perhaps premature to say anything at present, considering that the western portion of the lower Narbadá valley, where it is best developed,[1] has not yet been examined in detail. The lithological dissimilarity between the fine-grained, thin-bedded upper strata and the coarse conglomeratic deposits in which the oysters occur is great. But wherever the two groups are found together, there is perfect conformity between them; it is therefore highly probable that they are both of lower cretaceous age. Some light will be thrown on the question when the affinities of the

[1] "Manual," p. 295; "Memoirs," VI, pt. 3, pp. 145—185.

animals which have left clear tracks in the fine-grained upper beds of the Nimár sandstone have been satisfactorily determined. In the meantime, the fact of their occurrence shows that these have been deposited like the oyster-beds in shallow water close to the shore.

The lower portion of the Nimár sandstone, especially the very lowest, has a strong resemblance to the Gondwana beds of Kátkut and Barwái; both are equally unfossiliferous, yielding only pieces of drift-wood. But whereas no stratigraphical break has been hitherto observed between the former and the overlying deposits, a clear unconformity has been shown to separate the latter. Under these circumstances it is difficult to say with certainty whether the lower portion of the series under discussion is of the same age as the Barwái and Kátkut deposits: if different, the upper beds of the former overlap the lower; and if the same, there would be at least a local break in the series; but the section (that between Ágarwárá and Yálam) from which this conclusion is arrived at, is very obscure.

If the strata just considered be of Mahadeva age,—a point which is far from clear,—their western continuation may have some member or other of the lower Gondwanas at the base. Hitherto, however, nothing has been found to warrant such a conclusion.

CHAPTER VIII.

UPPER CRETACEOUS SERIES (AQUEOUS).

The series described in the last chapter is succeeded above by calcareous rocks, divisible into the following groups (in natural order):—

(iv)	Lametas . . .	(Lacustrine).
(iii)	Coral line limestone	(Marine).
(ii)	Deola and Chirákhán marl	(Marine).
(i)	Nodular limestone	(Marine).

None of these groups attains to any great thickness, and altogether they are nowhere more than 80 feet thick. Starting from the eastern extremity of our area, limestones with marine fossils are first met with

at Ghátiá; but there they are inconsiderable both in extent and thickness. At Ágarwárá and Yálam, also, their outcrop is equally insignificant, and, besides, is covered up by alluvium, being observable only in the beds of the little streams which flow past these villages. The strata roll about very much, especially at Yálam, owing probably to slight local dislocations. The thickness here does not exceed 15 feet; and the several groups are not clearly distinguishable.

Proceeding westward they are next found at Bowárla (10 miles west of Mándu). They thin out again in a western direction; and south of Káwant the case is just as it is near Barwái, the easternmost point of their occurrence. The Lametas occur throughout the area.

Section I.—The Nodular Limestone.

Name, area, &c.—The name, like all such derived from mere appearance or lithological character, is open to objection; for near Barwái and Káwant (the eastern and western extremities of our area respectively), the rocks representing it are not nodular. On the whole, however, the name seemed to me the best that could be given, in the absence of any towns of importance after which they might be called without giving rise to misapprehension.[1]

Between Bowárla and Phulmal (in the district of Áli Rájpur) the lithology of the group is remarkably persistent, being an argillaceous, whitish (or bluish white), compact, and characteristically nodular limestone. At Bowárla and Kherwán the base is not seen; near Káchâodá, in the northern portion of the Mán valley, it rests directly on the metamorphics; but at Chirákhán and westward, throughout the area, the Nimár sandstone is invariably present at the base.

The outcrop of the group is but slight, being mostly hidden by the coralline-limestone or the Lametas, to which it forms a fringe. The total average thickness is about 40 feet. It attenuates westward, but

[1] Bág is the only well-known town in the area where the limestone occurs. But as Bág beds have been used hitherto in a very wide sense (including all the limestones mentioned in the text above, as well as the sandstones described in the preceding chapter), I have avoided it to prevent confusion.

is nowhere entirely absent, being thus extremely serviceable as a stratigraphical landmark.

Palæontology.—Fossils are plentiful near Barwái, but scarce in the Mán valley. They abound, however, to the west of it. With the kind help of Dr. O. Feistmantel, Palæontologist to the Geological Survey, they have been roughly determined as follows :—

		AMMONITIDÆ.
e.	† †	1. *Ammonites guadeloupæ*, Roem.[1]
		GASTEROPODA.
e. (C. M. & U. G. S.)	†	2. *Fulguraria elongata*, d'Orb. (Stol.: Cret. Gast., p. 87, pl. VIII).
	* †	3. *Lyria granulosa*, Stol. (Cret. Gast., p. 99, pl. IX).
		4. *Fasciolaria rigida*, Stol. (Cret. Gast., p. 109, pl. X).
		5. *Triton* (sp.).
		6. *Natica* (sp.).
		7. *Cerithium* (sp.).
	§	8. *Turritella* (sp.).
		LAMELLIBRANCHIATA.
e. (Neoc.)		*Ostræa leymerii*,[2] d'Orb.
e. (G.)	§	9. *Inoceramus concentricus*, Parkins (d'Orb.: T. Crét., p. 506, pl. 404).
e. (G.)	§	10. *I. coquandianus*, d'Orb. (T. Crét., p. 505, pl. 403).
		11. *Inoceramus* (sp.).
e. (Neoc.)		12. *Modiola* (*Lithodomus*) *archiacii*, Leymer (T. Crét., pl. 344, figs. 10—12).
e. (Neoc.)		13. *Arca securis*, d'Orb. (p. 203, pl. 309).
	*	14. *Cardium* (*Protocardium*) *altum*, Forbes (Stol. Cret. Pelec., p. 221, pl. XII).
		15. *Venus* (sp.).
e. (Neoc.)		16. *Panopæa* (*Myopsis*) *arcuata*, d'Orb. (d'Orb., pt. 355, Agass. Moll. foss., pl. 31).
		POLYZOA.
	‡	17. *Ceriopora dispar*, Stol.

[1] In the list of Trichinopoly fossils given in the "Manual," this ammonite does not appear as a characteristic form. But see Stoliczka, Cret. Ceph., p. 92.

[2] Found only near Barwái and south of Káwant.

ECHINODERMATA.

e. ar. 18. *Hemiaster similis*, d'Orb. (T. Crét., p. 229, pl. 814).

N. B—The following signs and abbreviations used *before* a name imply:—

e = Also occur outside Asia and Africa.
a = Also occur in Africa.
ar = Also occur in Arabia.
C. M., U. G. S., G., &c., imply Chalk Marl, Upper Green Sand, Gault, &c.
* = Also occur in the Utátur group of the S. I. Cret. Series.
* * = Characteristic of do. do. do. do. do.
† = Also occur in the Trichinopoly do. do. do.
† † = Characteristic of do. do. do. do.
‡ = Also occur in the Arialur do. do. do.
‡ ‡ = Characteristic of do. do. do. do.
§ = Characteristic of the Central Indian cretaceous group in which the fossil in question occurs.

One of the most remarkable features of this fauna is the predominance of extra-Indian, and especially European, forms—ten out of twelve approximately ascertained species having been met with outside India, and of that number as many as eight in Europe. The presence of only one "apparently rare Utátur shell"—as Stoliczka remarks[1] about *Protocardium altum*—and that, too, by no means of common occurrence in the group under notice, is a fact quite as significant, and would appear anomalous, if we place this group, as we shall in the sequel, on a horizon not far removed from that of the South Indian Utáturs. The occurrence of several Trichinopoly forms would be another apparent anomaly. All these anomalies, however, may be explained on the hypothesis of a land barrier, separating at the *commencement* of the cretaceous period the South Indian, and probably also the Assam, Arakan, and South African basins, on the one hand, from the European, Arabian, and Central Indian basins, on the other. The gradual depression of this last-named area during the nodular-limestone (*i. e.*, early upper cretaceous) period—of which depression there is clear evidence, in that the fossils from this limestone are marine, whereas those from the underlying sandstone are estuarine—would submerge the supposed barrier, and thus allow intercommunication between the two sets of basins just mentioned. Some

[1] Pal. Ind.: Cret. Pelec., p. 222.

of the Central Indian nodular-limestone animals would then (about the middle of the cretaceous period) migrate southward and flourish in the South Indian seas during the deposition of the Trichinopoly beds; similarly, some of the South Indian Utátur forms would also about the same period migrate northward, and would be met with in the northern basin fossilised in beds stratigraphically higher than the Utáturs. That this is more than bare supposition is proved by the remarkable and hitherto unexplained fact, *that the forms which are common to the Utátur and the European cretaceous basins have an unmistakeably middle cretaceous facies.*[1]

Age —Bearing in mind the explanation just suggested, and considering that the majority of the characteristic forms occur on the horizon of the Étage Albien (Gault), there need be little hesitation in considering the nodular-limestone homotaxial with it, as well as with the lowest group of the South Indian cretaceous series (the Utáturs).

Section 2.—Deola and Chirákhán Marl.

Area, lithology.—Interposed between the group just noticed and the coralline limestone, to be described next, there is generally a band of argillaceous, almost flaggy, limestone, to which, as it is best developed in the neighbourhood of Deola and Chirákhán, the name heading the present section has been applied. Owing partly to its extremely small thickness, which nowhere exceeds 10 feet, and partly to its want of compactness and consistency, it has not been able to withstand the effects of denudation, when unprotected by the hard and crystalline coralline limestone; and, consequently, it hardly ever crops out at the surface; and when it does, the outcrop is too insignificant to be mapped.

Fossils.—When intersected by a stream or water-course, as at Oudiapurá (between Deolá and Chirákhán), Bowárlá, Kherwán, and Phátá by the Hátni (south-west of Bág), the marl yields a large number of easily available fossils; and all those collected by Colonel Keatinge were got from it at Oudiapurá and Chirákhán.

[1] "The general facies of the Cephalopodous fauna found in the lowest group, that of Utátur, approximates to that of the European Gault, but *nearly all the species of the other classes of Mollusca found in the same beds belong to a higher* horizon, cenomanien (upper green-sand) or even higher." (Blanford, "Manual," p. 291.) [The Italics are mine.]

The following have been roughly identified with the valuable help of Dr. O. Feistmantel. The significations of the signs and abbreviations prefixed to the names are the same as in the last section :—

		Ammonitidæ.
e.	† † §	1. *Ammonites guadeloupæ.*
		Gasteropoda.
e.	† † §	2. *Fulguraria elongata.*
a.	† † §	3. *Fasciolaria rigida.*
		4. *Turritella* (sp.).
		5. *Cerithium* (sp).
		6. *Natica* (sp.).
		7. *Triton* (sp.).
		Lamellibranchiata.
	‡	8. *Ostræa* (*Alectryonia*) *arcotensis*, Stol. (Cret. Pelec. p. 421, pl. XLIII).
e. a. ar.	* † ‡ §	9. *Pecten quinquecostata*, Sow. (Stol.: Cret. Pelec., p. 437, pls. XXXI and XXXVII).
	‡	10. *Radula* (*Acesta, Lima*) *obliquistriata*, Forbes (Stol.: Cret. Pelec., p. 421, pl. XXX).
	† §	11. *Plicatula multicostata*, Forbes (Stol.: Cret. Pelec., p. 446, pl. XXXIV).
	†	12. *Inoceramus multiplicatus* (Stol.: Cret. Pelec. p. 406, pl. XXVII).
	‡	13. *Pinna laticostata* (Stol.: Cret. Pelec., p. 385, pl. XXV).
e. a.	†	14. *Cardium* (*Protocardium*) *hillanum*, Sow. (Stol. Cret., Pelec., p. 219, pl. XIII).
	* §	15. *Cardium* (*Protocardium*) *altum* Forbes.
		16. *Venus* (sp.).
		Brachiopoda.
	† ‡	17. *Rhynchonella plicatiloides*, Stol.
		18. *Rhynchonella* (sp.).
		Polyzoa.
	‡	19. *Ceriopora dispar*, Stol.
		20. *Escharina* (sp. D)[1]
		21. *Eschara*, (sp. D.)[1]
		Echinodermata.
e.		22. *Cidaris cenomanensis*, Cott. (T. Cret., pl. 1052.)
e. ar.	§	23. *Hemiaster similis.*
		24. *Hemiaster cenomanensis* (D).[1]
		25. *Echinobrissus subquadratus* (D).[1]
	‡	26 *Orthopsis similis*, Stol. (Cret. Echin, p. 46, pl. VII).

[1] Those that are marked with "D" have been taken on the authority of Dr. Duncan's identification. (Quart. Journ., Geol. Soc., Vol. XXI, pp. 353, &c.)

VERMES.

27. *Vincularia* (sp. D).[1]

e. 28. *Serpula plexus* (D).[1]

ANTHOZOA.

e. 29. *Thamnathœa decipiens* (D).[1]

Age.—It will be seen that out of twenty species which have been determined with any approximation, seven are marked as characterising the group; of this number, three are equally characteristic of the Trichinopoly beds; one is common in, though not characteristic of, these beds;[2] one occurs in the Utátur group; one (*Hemiaster similis*) has not been met with in Southern India, but has been supposed to be allied to an Ariálur form (*Hemiaster rana*);[3] and the fourth has too wide a range, horizontally as well as vertically, to be serviceable for chronological purposes. Of the thirteen other species, five have been collected from the Ariálur group, one from the Trichinopoly as well, two from this group only, one (*Hemiaster cenomanensis*) has been compared to an Utátur form (*Hemiaster expansus*),[4] two occur in the middle cretaceous strata of Europe, and the remaining two are of little consequence for homotaxy. Two survive to the coralline limestone, and five have come up from the nodular limestone.

There is considerable difficulty in exactly correlating the Deola and Chirákhán marl to any of the three well-defined groups of the South Indian cretaceous series. But from the facts just set forth, it would not, I think, be unsafe to place it on a horizon approximately the same as that of the Trichinopoly beds. Had not *Ammonites guadeloupæ*, *Fulguraria elongata*, and *Fasciolaria rigida* (which are equally characteristic of the marly beds under consideration, and of the South Indian Trichinopoly group) made their first appearance in the nodular-limestone sea, the fact of their being more highly organised than the Acephalous

[1] Those that are marked with " D " have been taken on the authority of Dr. Duncan's identification. (Quart. Journ., Geol. Soc., Vol. XXI, pp. 353, &c.)

[2] Pal. Ind.: Cret. Pelec., p. 446.

[3] Quart. Journ., Geol. Soc., Vol. XXI; "Manual," p. 297.

[4] Ditto ditto ditto.

Mollusca and the Echinodermata that are common to the Deola-Chirákhán marl and the Ariálur strata, coupled with the presence of several European cenomanian forms, would have helped us to fix the geological position here suggested with greater precision.

Section III.—The Coralline Limestone.

Name.—This limestone, owing to its extensive use as the principal building stone in the Nimár valley, especially at the now ruined Mahomedan town and fort of Mándu, attracted the attention of some of the earliest observers. As early as 1822,[1] Mr. J. B. Fraser noticed it in the buildings of Mándu, and speaks of it simply as a "reddish limestone of a beautiful and remarkable character."[2] But the editor of the Geological Transactions, in which Fraser's paper appeared, has a foot-note describing the specimen of limestone presented by Fraser to the Geological Society as containing "fragments of coral and small specks of quartz." This is, I believe, the first mention of supposed corals in the limestone destined to become so well known under the name of "coralline." It was, however, not until 1854 that it was so christened formally by Dr. Carter.[3]

Area, lithology, &c.—The coralline limestone of Ágarwárá, near Barwái, has been already alluded to. It is next found at Bowárla, overlying the group last described. It thins out westward and southward, the maximum thickness (about 30 feet) being found in the Mán valley, between Deolá and Káchávda, and between Nimkhera and Ghursul. Near Tándá, only a few patches, as at Dhaeri and Kherli, not more than 3 or 4 feet in thickness, were met with. West of the Wágni it is rare, having been noticed at only a few places, such as Khándlái, south-west of Bág, Phátá by the Hátni, &c.[4] But it has been traced to as far west as Umráli, near Áli. It is wanting in the district of Káwant.

[1] About the same time Dangerfield noticed the limestone *in situ*, probably in the neighbourhood of Chirákhán and Ghursul.

[2] Geol. Trans., Ser. 2, Vol. I, p. 156.

[3] Journ. Bomb. Br. R. A. S., Vol. V, p. 237.

[4] Amongst Mr. Fedden's collection of the season 1880-81, from Kattiwar, there are specimens of polyzoan limestone which look very much like the "coralline."

The mineral character and general appearance of the limestone has been well described by Mr. Blanford[1]:—

"It is yellow or red in colour (the former tint being doubtless due to some carbonate of iron, in the limestone exposed to the air, being converted into peroxide), and consists chiefly of small fragments of *Bryozoa*, shells, &c. The fresh broken surface has a somewhat granular mottled appearance, and the fossils are not conspicuous; they weather out on exposure. In many places this bed is obliquely laminated."

The limestone, though it rolls about at places, is, like the two groups described in the previous sections, as a rule, horizontal. But north of Ajantár they are all carried with the same dip, which is northerly and amounts to about 15°, and are faulted against the Nimár sandstone.[2] South of Ráherdá, only 4 miles further north, they dip southward at about the same angle.

Palæontology.—The following fossils have been obtained from the limestone:—

LAMELLIBRANCHIATA.

1. *Ostræa* (sp.).[3]

BRACHIOPODA.

† ‡ § 2. *Rhynchonella plicatiloides.*
3. *Rhynchonella* (sp.).

POLYZOA.

‡ § 4. *Ceriopora dispar.*

ECHINODERMATA.

e. 5. *Hemiaster similis.*
e. ar. § 6. *Cidaris cenomanensis.*

Age.—This number is, perhaps, too small to reason upon. But the disappearance of all the most characteristic forms of the underlying beds has to be noted; and the special prominence and abundance of forms which had occupied a very subordinate position in the fauna of the

[1] "Manual," p. 294.
[2] See *ante*, p. 25.
[3] This was obtained only in the neighbourhood of Chirákhán, and appears to be local.

latter, indicate considerable changes of physical conditions, and consequently a proportionate lapse of time.

The remarkable change in the mineral character also proves a corresponding alteration in the configuration of the cretaceous sea, and, therefore, in the physical geography of the country from which the rivers derived their sediment.

On these considerations, and on the strength of the fact that two of the most characteristic forms occur in the highest (Ariálur) division of the South Indian cretaceous series, I am inclined to correlate the coralline limestone, of course roughly, with the latter.[1]

Section IV.—Lametas.

Area, lithology, &c.—A small patch of unfossiliferous limestones, quarried for building purposes, occurs 2 miles south of Punghát, in the western portion of the district of Hoshangabad (map No. 1). They are probably Lametas.

North of Punássá (map No. 1) there are some horizontally bedded gritstones and conglomerates deposited in a hollow in the Vindhyans. The colour of the matrix resembles that of the latter, which is no doubt owing to the detritus being derived from them; and on stratigraphical grounds I have no doubt that the rocks in question are not Vindhyans. But they may belong to the Gondwana sandstone. Their remoteness, however, from the known outcrops of this series, and proximity to beds with fresh water shells of inter-trappean affinities, seemed to me to be in favour of their being nearer in age to the latter.

At Bhorlá (2½ miles north-east of Punássá), the conglomerates just mentioned are noticed in the bed of a tank, covered by black soil over-

[1] At Kherwán, and in the vicinity of Deola and Chirákhán, fields of coralline limestone are strewn over with pieces of what appear to be jaspidified wood. Between Chirákhán and Deola, just by the road-side, there is lying a fossilised tree, but the silicification has gone so far as to render its identification extremely difficult, if, indeed, possible. This is most likely the fossil trunk noticed by Colonel Keatinge in January 1857. (Journ. As. Soc. Ben., Vol. XXVII, p. 121).

grown with long, almost impenetrable, grass.[1] A few yards west of the tank limestone with fossil shells is seen. Its exact relation to the conglomerates could not be made out. The limestone is overlaid by the trap to the north; in the south, the basaltic rocks abut against it; and I could not ascertain whether the bed in question was inter- or infra-trappean. I had the same difficulty a little further south, 2 miles west of Punássá. The limestone is traceable with but little interruption to Pipri, 4 miles south-west of this town; and by the road a little to the east of the village it is clearly seen to lie between the traps, and has therefore been mapped as "inter-trappean;" but it is not unlikely that a portion of it may also be Lametas.

At Ákhkund, the Gondwana sandstone passes above, as has been noticed before, into calcareous strata, with a few feet of pinkish marls at the top containing *Physa prinsepii* in abundance. The trap overlies them; and the beds are unquestionably infra-trappean. This is the only instance of the occurrence of fossils in the Lametas in the area comprised in this memoir.

At Bowárla (west of Mándu), between the coralline limestone and the trap, there is a pinkish marl not unlike the rock just described, which is probably of the Lameta age.

But it is south and west of Bág that the Lametas occur in great force, forming a flat, high-level tract covered with thin, low jungle. Of hardly sufficient thickness in the eastern portion of this area to be dignified with any distinct appellation, it becomes more than a band at Kherli and Jogardi, and increases in thickness further west, as at Indwan and Phátá, in the Hátni valley. The maximum thickness would be about 40 feet, and the average 20 feet. Cherty limestone, usually white, but sometimes mottled, is the principal constituent of the group. South of Káwant the rock is coarsely conglomeratic.

[1] The whole country south of the Narbadá between the Chhota Tawa on the east and the Cavery on the west, north of Punássa, being a reserved forest, there are but few roads, and hardly any villages or encamping grounds. The grass (which it seems is not allowed to be cut down, except along what are called "lines") was too long to allow the rocks to be observed closely. Fortunately, the ground is chiefly Vindhyan, with only a few outliers of the Deccan trap.

Age.—In correlating the marine limestones of Bág with the fresh-water limestone (Lameta) of the Upper Narbadá, Mr. Blanford suggested that the cherty character common to both might be due to the action of superincumbent trap.[1] That such is not the case is perhaps sufficiently shown by the fact that, when the trap rests on the undoubtedly marine limestone, no such effect has ensued; as near Ghursul, &c. But the cherty limestone of the Lower Narbadá valley, besides overlapping, is clearly distinguishable from, the underlying beds described in the previous sections: first in the absence of marine fossils; and, secondly, lithologically. We therefore suggest the correlation of the cherty band alone with the Lametas.

Mode of deposition.—In the western portion of our area the Lametas generally rest upon the nodular-limestone; at places the Deola and Chirákhán marl and the "coralline," or the "coralline" alone, intervene. The manner in which these latter groups have been preserved—only in small patches at wide intervals—would tend to prove the denudation they had suffered to have been marine: and the Lameta beds appear to have been deposited in, perhaps, brackish lakes formed in the course of the movement of upheaval during the upper cretaceous period in the western portion of the Central Indian cretaceous basin.

In the Nimáwar-Barwái area the Lametas are clearly of fresh-water origin.

Passage into agglomerates.—In the Káwant area the Lametas present no little difficulty in mapping, passing, as they do almost imperceptibly at places, into stratified beds of volcanic ejecta. These beds are thickest between Siriwasan and Mánkui, and thin away in all directions except the southern, where they are continued as far as Mongra, sending off an arm westward. Beyond Mongra they stretch away southward probably for some distance. They are met with as stragglers near Ráisingpura. Here, as well as between Mongra and Mánkui, the agglomerates have a decidedly trappean look, with angular fragments of basaltic rocks scattered in the matrix, associated with similar

[1] Manual, pp. 295; Memoirs, Vol. VI, pt. 3, p. 54.

fragments and blocks, occasionally a foot or so in diameter, of Nimár sandstone more or less baked. Traced northward beyond Mánkui, they assume a sedimentary aspect and pass into Lametas, in a most bewildering manner. Reddish calcareous sandstones are inter-stratified with them at Ghántol. Here they attain a thickness of some 200 feet. But the lower portion of this thickness is chiefly made up of Deccan trap beds. These are in all likelihood intrusive; if so, the sandstones would belong to the Lametas, and may be supposed to have been thrust upward by trappean intrusions along with the overlying tuff. The fact that similar sandstones occur in the Lametas about Bág gives colour to this supposition. But whether they are Lametas or not, from their perfect conformability with the superincumbent agglomeratic strata, it is evident that the latter accumulated in Lameta lakes or lagoons, or, in other words, were continuous, as it were, with the deposition of the Lametas. The prevalence or otherwise of volcanic showers owing to the proximity or remoteness of a focus of eruption, as well as to the direction of the wind, &c., would give these latter an igneous or sedimentary aspect.

Besides the angular fragments of trap and Nimár sandstone, there are present in the agglomerate or tuff those of older rocks, especially and remarkably of a highly crystalline saccharoid limestone[1] and of a syenitic rock. Crystals of augite also occur, and are very serviceable in distinguishing them. At Ártiá, for instance, there is a highly sandstone-like tuff resting upon trap, and, but for the presence of the volcanic mineral, might be mistaken for some bed of the Nimár sandstone brought up by igneous intrusion.

The presence of the agglomeratic strata indicates the existence of a volcanic centre; and their thickness and association with huge angular blocks of pre-trappean rocks show that the igneous centre was not far. In fact, from the manner in which they are cut off by the basaltic ridge at Nákál and Mánkui, it is not unlikely that the traps composing this ridge were erupted out of a fissure in the locality.

Their stratification, the presence in them of sedimentary material,

[1] This is undoubtedly metamorphic limestone altered by heat.

and the almost imperceptible passage, at places, into Lameta conglomerates, are favourable to the supposition of the agglomerates having been deposited in water. Their extension southward and great thickness would prove the sheet of water in which they were deposited to have been either a lake deepening and widening to the south, or an arm of a sea situated in that direction.

Section V.—Recapitulation and General Remarks.

Summary of correlations.—The following correlations have been suggested in the previous sections:—

L. Narbada Valley.	*Southern India.*	*Ind. and Burma.*	*Europe.*
Lameta	Lameta (?)[1]	......	Senonian.
Coralline limestone	Ariálur	......	Senonian.
Deola and Chirákhán marl.	Trichinopoly	Ramri Island[2]	Turonian. Cenomanian (part).
Nodular limestone.	Utátur	Khási area[3]	Cenomanian (part). Albian.

These conclusions would appear to be at variance with that suggested by Keatinge, worked out by Duncan, and accepted by Blanford,[4] *viz.*, that the "Bág" rocks (in the widest and hitherto accepted sense of the expression) are assignable to about the same horizon as the upper greensand, and "must in consequence," as remarks Mr. Blanford, "closely correspond to the Utátur group of Southern India."[5] But, considering that the data upon which this inference was based were still more insufficient than those collated in the present report, it in reality rather tends to corroborate than otherwise the homotaxy indicated here. The fossils collected by Keatinge and described by Duncan were all from

[1] See King: "Memoirs," Vol. XVI, pt. 3, p. 42.

[2] In the palæontological collections of the Geological Survey of India there is a fragment of an ammonite, supposed to come from the Ramri island, on the Arakan coast, which resembles very closely a variety of *Ammonites guadeloupæ* in my collection. I do not, however, find any mention of it in the "Manual." Lieutenant W. Foley, who seems to have presented it to the Asiatic Society along with two or three others, is also reticent on the point (see Journ. As. Soc. Ben., Vol. IV, p. 20).

[3] The fossils from the Khasi hills have not been described yet.

[4] Q. J. G. S., Vol. XXI, pp. 353, &c.; "Manual," pp. 296, 297.

[5] "Manual," p. 297.

the Deolá-Chirákhán marly band;[1] and no organic remains have been hitherto definitely known from either the nodular limestone or the sandstones to which the designation of "Nimár" has been here appropriated.[2] And no clear physical unconformity having then been detected between any of the five lithologically distinct groups interposed between the Bijawurs and the trap, they were all incorporated into one and the same series, and on the strength of the evidence afforded by the fossils (especially Echinoderms) of the Deolá and Chirákhán marl, referred to the horizon of the European cenomanian. It will be seen from the table of correlations just given, that this marl has been here also located at about the same horizon.

Characteristics of the fauna.—It may be remarked about the fossils, that though rich numerically, so much so that at places cart-loads could be collected with but little difficulty, their poverty as regards variation, amounting to generic or even specific distinctions, is most noteworthy. I collected, for instance, over 100 specimens of ammonite, all in a fair state of preservation, between Bowárlá and Muráso, about 50 miles apart, and at all horizons, from the base of the nodular limestone to the top of the infra-coralline argillaceous limestone. But they all proved to belong to one species. Yet they present so many varieties, between the extremes of inflation and compression, as well as of shape and size, that at the time I was unearthing them, I had an idea that several species would have to be made out of them.[3] They, as well as the varieties of such forms, as *Hemiaster*, &c., offer a splendid illustration of Darwin's well-known law, that wide-ranging, much-diffused, and common species vary most.

[1] "Beneath it [the "coralline"] is an impure, argillaceous limestone, from which all the fossils of the Bágh beds hitherto procured in this neighbourhood have been obtained." (Blanford, "Manual," p. 295.)

[2] "The limestone [nodular] is nearly unfossiliferous; only here and there a fossil occurs in it, and the few specimens found are but rarely well preserved." ("Manual," p. 95). See Memoirs, Vol. VI, pt. 3, pp. 47, 49, &c.

[3] In one of the specimens of ammonite in my collection, there is a piece partly imbedded in the matrix, which appears to be that highly important but rarely seen structure, known to palæontologists as "aptychus."

Physical geology of the Cretaceous basin.—The following points have been already indicated :—

(1) The nodular limestone becomes attenuated westward; west of the Wágni river it is highly fossiliferous, but east of that river fossils are rarer.

(2) The argillaceous limestone, and the overlying coralline limestone also, both thin out to the west; and west of the Wágni, they have been noticed at only a few localities, forming short and narrow bands.[1]

(3) The Lametas, unlike the groups just mentioned, thicken westward, and rest generally upon the nodular limestone.

The resultant movement of slow terrestrial depression which had been going on in the neocomian sea (the northern configuration of which probably coincided with the southern outline of the present Vindhyan range) continued during the earliest portion of the upper cretaceous epoch. But towards the end of the nodular-limestone age, a general, gradual, elevating movement set in west of the Wágni, lasting very nearly until the conclusion of that epoch; and the subsidence became restricted to the area east of the Wágni, until the deposition of the coralline beds, when the movement was reversed. Thus the attenuated condition of the nodular limestone in the western portion of the cretaceous basin would be accounted for by its having been subjected to marine denudation, while raising its head above the sea, and its greater thickness eastward, would be attributed to its preservation in a subsiding bay. The argillaceous and coralline limestones would be well protected and deposited in greater and increasing depths in the latter area; whereas, in the former, they would be so liable to be removed the moment they were thrown down, that not more than a few patches could be expected to be preserved. We should expect the organisms that lived in the coralline sea to have been deeper-sea forms than those imbedded in the Deola and Chirákhán marl, and such is the case.

[1] In his necessarily hurried preliminary survey Mr. Blanford did not notice these bands (see Manual, p. 295).

The basin in which the marine cretaceous deposits near Barwái were deposited was probably distinct from that to the west of Mándu, but like the latter probably deepened to the south-west also.

CHAPTER IX.

Upper Cretaceous Series.

(Igneous.)

Lithology.—I have little to add to the general lithology of the remarkable series of horizontally-bedded igneous rocks so well known under the name of "Deccan Trap." The alternation of basalt with vesicular or amygdaloidal rocks of similar composition, and the abundance of zeolitic and calcareous minerals of various forms and sizes, and of geodes of agate or chalcedony frequently filled with crystals of quartz, are too characteristic to have escaped the attention of earlier observers, such as Dangerfield[1] and Fraser.[2]

The rocks which have been referred to this series are nearly all basic. Those forming dykes are more or less crystalline, invariably more so in the centre than at the sides. They occasionally occur in columns, but the usual form is massive. The principal constituents are plagioclastic felspar, augite (mostly as grains), and magnetite. The first is the most abundant and conspicuous, and sometimes occurs in large crystals.

Lavas.—These form the Malwa plateau. They generally occur in beds of compact basalt with an amygdaloidal upper portion. Several such beds may be counted at Jám Ghát where the winding road well exposes them to observation. The basalt has a micro-crystalline structure

[1] Malcolm's "Central India," Vol. II, pp. 328, &c., "Geol. Pap. on West Ind.," p. 231.

[2] Geol. Trans., Ser. 2, Vol. I, pp. 116, &c.

The descriptions of Sykes (Geol. Trans., Ser. 2, Vol. IV, pp. 411, &c.) and Malcolmson (Geol. Trans., Ser. 2, Vol. V, pp. 537, &c.), though referring particularly to the Deccan and Central Provinces, are also partially applicable to the general lithology of the trap formation in the Malwa area.

with numerous minute, beautiful, little, clear needles, which are undoubtedly of plagioclastic felspar, as they are not unfrequently observed to build up by aggregation crystals exhibiting in polarised light the colour bands so characteristic of that mineral. It is also present in larger crystals as in the doleritic dyke rock, so large as to be visible to the naked eye, and sometimes in such numbers as to render the rock almost porphyritic. There can be little doubt that it is this mineral which has been sometimes taken for orthoclase looking as it does remarkably like sanidin. This species of felspar (orthoclase) is rare, as might, indeed, be expected, in the basic rocks under review; it occurs as a normal constituent only in the Káwant rock, and in a few other instances to be noticed presently.[1] Augite, coloured brownish, is common, but usually too small to be visible with the naked eye. Very few well-developed crystals of the mineral have been observed. They hardly ever show the characteristic cleavage, but the cracks of which they are full indicate it in some. The only other mineral which, besides magnetite, claims notice, is olivine. Its distribution is very local,[2] but when it is present the crystals are good and well formed, and are beautifully seen on the weathered face. (See Plate, fig. 1.)

The minerals formed by infiltration in the vesicular beds, converting these into amygdaloids, have been fully noticed by previous observers, being most conspicuous and therefore striking.[3]

Agglomerates and Ashes.—Beds of considerable thickness formed of volcanic ejecta were noticed in the last chapter. Strata of volcanic ash occur, especially at the foot of the Vindhyan range, as between Mahesar and Jám Ghát. Ferruginous, marly-looking, pinkish beds from an inch

[1] Mr. Blanford in his paper on the "Traps and Intertrappeans" describes the felspar in the trap as "glassy felspar" (Mem., VI, Arts. 5, 6). The following passage occurs at p. 305 of the "Manual" ". . . . . . and the only felspar which occurs in distinct crystals appears to be the form of orthoclase (glassy felspar), &c."

[2] Its absence from the Bombay basalts has been noticed by Colonel McMahon ("Rec.," Vol. XVI.)

[3] At Muraja, south of Umráli, in the district of Ali Rájpur, I met with curious agate-geodes in a calcareous matrix. The calcareous substance has been substituted by infiltration for the trappean, until hardly any trace of the latter has been left, by a process similar to the silicification of wood.

to several feet in thickness were met with at several points along the Vindhyan range, as at Garaghát, north of Gujri, Jám Ghát, Ámjherá, &c These have been known as "red bole." Should they prove to be continuous, their importance would be more than local, if we regard them as burnt trap soil;[1] for their number would then correspond with the different stages of eruption.[2] Fragments of an ashy rock with numerous bits of wood, all apparently belonging to one species of plant, were picked up at Umráli on the Hátni in the district of Dei. The rock was not seen *in situ*. It was no doubt formed in some pool during an eruption.

Dykes.—These are met with throughout the valley. They are abundant in the Chándgarh-Hándiá metamorphic area. The main dykes (averaging 10 feet in breadth) invariably take an east-west direction—the strike of the metamorphic schists; the branches varying from 1 to 6 feet in breadth run in all directions, pursuing a tortuous course which appears to have been determined by the cracks in the rocks intruded through. The rock composing the principal dykes is a coarse dolerite with large and conspicuous triclinic felspar, and weathers into globular masses. The branches, however, are often of a compact, fine-grained rock, indistinguishable microscopically from basalt.[3]

North of Pamákheri in the district of Chándgarh (Map No. 1), there are seen close to the road to Sirka Talao globoid masses of large-grained dolerite; traced westward, these are lost under vesicular basalts occupying the valley between two hills of Vindhyans. It is highly probable that the basalts flowed out as lava from the fissure in which has consolidated the plutonic rock just mentioned.

[1] Judd, Quart. Journ. Geol. Soc., Vol. XXX, p. 7277; see also Lyell's "Principles," Vol. II, 10th Edition.

[2] I counted three seams of the red soil (if soil it be) in my ascent up the Jám Ghát to the Malwa plateau. Sykes describes the "red bole" as ferruginous clay (Geol. Trans., Ser. 2, Vol. IV). Mr. Blanford is inclined to look upon the "red bole" as a form of volcanic ash. (Mem. VI, pt. 2, p. 7; see also Hislop, Quart. Journ. Geol. Soc., Vol. XI, p. 364.)

[3] Great care must be taken to distinguish the true dykes from fine-grained, hard, black, shaly veins which occur in the metamorphics, and are most plentiful about Punghát, Fategarh, &c. It was not until I submitted the latter to microscopic examination that I became quite sure about their real nature.

At Chándgarh, the trap is seen superposed on the metamorphics. Further west, however, it occupies the valley between ridges of Vindhyan rocks, as near Pamákheri. The fact of the occurrence of a dyke a mile and a half north of the place, as well as of another (slightly exposed) at Sákerghát, makes it almost certain that this trap was erupted out of a local fissure.

In the bed of the Narbadá, at Boriá, two miles south-west of Chándgarh, a good dyke is seen striking very nearly east-west. It runs pretty straight down to Jámoti (or Palási), masses of the Bijáwar limestone being found resting on it at places. At the last-mentioned place, it apparently divides, passing round an island composed of highly disturbed, nearly vertical, Vindhyans; the northern branch is lost under deep water, but reappears at the western end of the islet; the southern branch is traced to some distance and then lost under the Vindhyans.

Numerous small dykes occur between Chándgarh and Mándhátá. These are, however, not traceable to any considerable distance.

The columnar dyke in the Dhár forest has been already described; there is a similar dyke in the Deccan-trap at Palási in the north-eastern corner of the same forest, close to the Vindhyan range. Here, too, it forms a hill elevated a couple of hundred feet above the general level of the valley; the columns are horizontal, except on the northern face of the hill, where they are highly inclined.

There is another dyke hill of horizontal columns also in the Deccan trap, two miles north of Tharwa (near Kátkut).

Opposite the town of Mandlesar (once the seat of a small British cantonment) there is seen in the bed of the Narbadá in the dry season a low ridge running in a north-east—south-west direction. The rock composing it is found to be crystalline, the central portion being much more so than the lateral. The triclinic felspar is quite large enough to be well seen with the unassisted eye; the augite is also large, coloured dark brown, irregular, and full of cracks. [See Plate, fig. 2.]

The texture of the rock, and the straightness of the direction in which the ridge runs raise a presumption in favour of its being

regarded as a dyke—a conclusion which is confirmed by the blocks (to be noticed presently) carried up by it not occurring, as observed by Mr. Blanford, "out of one general line."[1] These blocks are of a greyish-looking rock, which, owing probably to the pleasant contrast they present to the black rocks of the district, have attracted the attention of several observers.[2] The largest of the most readily accessible is 30 feet in length and 14 in breadth. It is separated by an oblique crack into two unequal and lithologically distinct portions, one being much more coarse-grained than the other.[3] The rock is described as granite by all previous writers. The specimen taken, close to the contact with the dyke, is rather a felsite, with crystals of quartz, felspar, and mica imbedded in a micro-crystalline ground-mass. The quartz contains a large number of liquid cavities besides plates of mica. The felspar is considerably decomposed, appearing as cloudy patches, and merely changing shades in polarised light. The microliths (probably felspar) making up the ground-mass appear to assume a sort of wavy or radiating arrangement.

For about two inches of the contact with the crystalline dyke-rock described above, the felsite is irregularly altered, small patches of the unaffected rock being traceable nearly down to the very contact. In the altered portions (which are coloured more or less dark) the quartz appears smaller, dirtier, and less numerous, but is still clearly recognisable; the other minerals, however, and the characteristic matrix have entirely disappeared, and in their place we find a crowd of long, slender, and altogether singular-looking crystals which, together with trichites and a few grains of what look like magnetite, are interspersed in a matrix of crypto-crystalline texture. These crystals are quadrangular in transverse section. Some show a clear peripheral and a granular dusky central portion; irregular stone enclosures abound in the former, and the cloudy central portion appears in several cases to protrude from the matrix. Others are dirty throughout with minute granules. Others, again, enclose parallel rows of squarish black grains. In polarised light, bright

[1] "Memoirs," Vol. VI, pt. 3, p. 129.

[2] See Transactions, Bombay Geog. Soc., Vol. VI, p. 7; Journ. A. S. B., Vol. XIV, p. 821.

[3] The crack may be a small fault.

colours (not in bands) are exhibited by the clearer portions. The mineral is probably felspar. The heat from the dyke must have partially fused the felsitic rock; the quartz managed to survive, though considerably injured; the other minerals succumbed and were melted. The doubtful mineral (probably felspathic), described above in detail, crystallised out of the molten mass under considerable pressure no doubt, but rather quickly, as is evidenced by the numerous stone enclosures. The country about Mandlesar, like the rest of the trap country, was quickly traversed, and a closer examination may result in the discovery of more dykes or branches of the dyke described in the preceding paragraphs. The hugeness of the blocks carried up by it, and the manner in which they have been altered prove the intensity of the igneous force at the place, and a volcanic centre was probably at hand. This supposition receives confirmation from the thickness of the ash-beds below Jám Ghát, a few miles north of Mandlesar, though the ash is fine-grained, and may have come from far. No agglomerates like those noticed in the Káwant area were met with. But their absence may be attributable to the sub-aerial origin of the trap about Mandlesar, and the greater liability of loose heaps of scoriæ to be destroyed by denudation than stratified beds of the same material like the Káwant tuff.

The hills west of Barwáni (outlying spurs of the Sátpura range) exhibit a number of dykes running in an east-west direction. The number and extent of these could not be ascertained, as the district was very cursorily examined. Several were noticed near the ancient fort of Rájgarh by the Goi river. These were found to be composed of two widely different kinds of rock, one basic crystalline like the dyke rock at Mandlesar, the other a singular felspathic rock. The latter is very hard, harder than the trap of the neighbourhood, and in consequence invariably forms the summits of ridges, being thus visible from far. It consists of small, whitish, irregular crystals of decomposed felspar (orthoclastic) interspersed in a brownish amorphous base. The rock appears to be a felstone.[1]

[1] These dykes are alluded to by Mr. Blanford as "peculiar brecciated veins." He attributes them to small faults. (Mem. VI, pt. 3, pp. 106 and 107.)

Similar dykes of felstone are met with along the Narbadá between Dei and Dharamrái. In the bed of the river opposite this latter village, as well as in several sections exposed in the neighbourhood, a similar felstone occurs interstratified, as it were, with the traps. It was probably erupted as lava through the channels just mentioned; and the irregularity of the underlying basaltic surface would prove it to have suffered from previous subaerial denudation. The sheets, it may be remarked, extend for very short distances. A few miles north of Dharamrái, east of Atarsuma, just south of the road between Dei and Kuksi, there is a conical hillock not raised more than a hundred feet above the surface. Its body is made up of the Deccan basalt; but along the sides are several narrow and thin streams of a felspathic rock with brownish veins of limestone. They hardly reach the base; above they are traced to the summit of the hillock, which is circular in shape, and is not unlikely the base of the crater from which they were poured out, the hollow of the crater itself having been denuded away.

The only other localities within the area examined by me where non-basic igneous rocks occur in any quantity have been noticed in connection with the Káwant trachyte. Mr. Blanford, however, describes several trachytic intrusions further westward, such as at Matepanai hill, Pudwáni, &c.[1]

The Káwant trachytes, inasmuch as they are overlaid and cut across by what are apparently the lowest beds of the Deccan trap, are of pre-trappean age, and afford, therefore, a normal case of the order of volcanic outbursts. The Barwáni felstones, on the other hand, are an exception to that order, for their intrusion was effected through fissures in the basaltic flows, and must consequently have been posterior to these.

The district of Dei furnishes numerous interesting instances of dykes and irregular intrusions, which prove it to have been a volcanic centre in the Deccan trap age. About the town of Dei and between it and Dharamrái, there are sundry small straggling inliers of pretrappean cretaceous rocks, cut through by the traps which have frequently forced up

[1] "Mem." VI, pt. 3, p. 59; "Man.," p. 327. Mr. Fedden also has met with trachytic rocks in the Deccan trap in Kattywar.

some of their beds, tearing off and scattering broadcast angular blocks derived from them.

At Málpur, between Karajwáni and Temrio, by the road to Dei, there occur masses of crystalline dolerite weathering into large-sized exfoliating nodules. They are exposed only for a few yards, and are lost under beds of Nimár sandstone and upper cretaceous limestone, the sandstone close to the junction being altered into quartzite. The surface of the sedimentary rock in immediate contact here (and in a few other cases) has been smoothed and scratched with parallel grooves as if by faulting. But there was no other sign of any such dislocation noticeable in any of these cases; and the striation of the contact surface appears to have been produced somehow subsequent to its fusion or semi-fusion by the heat of the intruded rock.

About a mile westward, south-west of Karajwáni, there runs in an east-north-east—west-south-west direction, almost in a line with the doleritic dyke just noticed, another of rather compact, fine-grained dolerite [1] exposed to observation with trifling interruptions for over three-quarters of a mile. The sandstones immediately in contact have been variously, and as if whimsically, altered. The alteration, however, does not extend beyond half a foot in any direction; nor are there any signs of disturbance in the uplifted strata.

At Narjuli, east of Málpur, there is a dyke running as a ridge, with yellowish, baked, pre-trappean rocks at its summit.

These three dykes are almost in a line and probably connected underground. At Cháklio, 2 miles north of Dei, a small dyke of basalt is exposed, and I have no doubt several similar ones occur in the district.

At Phátá, at the northern extremity of the Dei area, a dyke is cut through by the Hátni. It is of a coarsely crystalline rock, similar to that of Mandlesar, Barwáni, Málpur, &c., passing above and at the sides into a much finer grained dolerite. The sandstones in contact are remarkably altered.

The cretaceous tract west of Dei has been broken through by innumer-

[1] The rock is so named from its crystalline structure as seen under the microscope. To the naked eye it, like several other dyke-rocks, appears a basalt.

able igneous intrusions. One of these forms a ridge broken at Jolwát evidently by denudation. It is capped by masses of a peculiarly altered, brownish calcareous rock, so often alluded to in the preceding pages,[1] and terminates at Kulwat by the Hátni in a tract of altered infra-trappeans similar to that from which it originates. The altered rock is harder than the trap, so that it stands meteoric degradation better than the latter, and forms the peaks and summits of trap hills. This circumstance, as well as its colour, led me at one time to confound it with the Barwáni felstone. But the former is markedly calcareous, whereas the latter is not so, except on the weathered surface; besides, felspar crystals are abundant in the one, but quite absent in the other. There are other points of difference, as will be presently seen. The rock in question is so common in the trap country west of the Hátni, south of the metamorphic and cretaceous tracts, that it demands a few lines of detailed notice.

The following characters may be tabulated :—

1. It is usually found in unbedded masses at the top of trap hills and ridges.
2. These ridges are of a rather compact and fine-grained but crystalline rock (dolerite) forming in several cases the lateral portion of dykes with markedly crystalline rock structure at the centre.
3. The ridges run in a line generally in an east-western direction.
4. The rock under notice is at places associated with highly altered and intensely hardened shaly and silicious rocks.

But the most marked peculiarity of the rock, and that which above all renders its lithology most puzzling, is the presence in it at places of nests and patches of a trappean-looking substance, the igneous origin of which is manifest under the microscope. Considering, as I did at starting, the strange rock as inter-trappean, owing to its invariable superposition on the trap, I accounted for the presence of the volcanic matter in it by the showering of the former into the lake or sea, in which streams were depositing calcareous sediment in inter-trappean times and getting mixed

[1] See pages 27, 30.

up with that sediment. But I had soon to change my mind. The rock is unlike any known inter-trappean, and has nowhere yielded a trace of a fossil. Had it originated in inter-trappean lakes or lagoons, the outcrops could not have been so uniformly linear and straight and of such fragmentary character.

From a consideration of the vicinity of pre-trappean beds (the Nimár sandstone with the overlying upper cretaceous limestones), and the occasional association of altered shales and sandstones, there can be very little doubt that, in common with these, the rocks under notice have been severed and forced up from the infra-trappean beds by intrusive rocks. They have been most effectually baked, being rendered quite crystalline, the colour changed with remarkable uniformity into yellowish or reddish brown; and, what is most remarkable of all, portions of them would appear to have been converted into a trappean substance. A somewhat analogous transformation has been noted in connection with the Mandlesar dyke. But in the present instance the change is on a much larger scale.

To the explanation just offered of the origin of the strange calcareous rock, there is one serious objection. We have seen in several cases that the heat from dykes has affected the strata in contact only to a small extent. In the case at hand, however, several feet of the rock have been supposed to be fused, and to such a degree as to be partially converted into patches of a lava-like substance. The greater intensity of the igneous force in this case, as is indicated by the up-lifting of rock-masses through several score feet, perhaps explains the difference in part. But the fact that these masses, however huge, exert considerably less pressure when torn off from their parent beds than when *in situ*, and thus become more liable to fusion, probably accounts for a great deal more.

Several cases of columnar structure have been already noticed; an approach to it is observable everywhere throughout the area. Perfect basaltic colonnades were met with by the Uri at Mángdi, about a mile and a half south-east of Tándá; by a streamlet which, originating from close to the Tándá-Dehri road, joins another at Jámla (three miles and a half north-west of Bág); at Aolia (7 miles south-west of Bág), &c.

The Mángdi columns are seen for about half a mile along the left (eastern) bank of the Uri, north-east of the village; after an inter-space of about a quarter of a mile of metamorphics, they are again seen along the right (western) bank of the river for about a quarter of a mile south of the village.

The more northerly of these columns are distinctly divisible into an inner and an outer portion. The former exposed along the Uri, nearly up to its junction with a streamlet which flows past Chunpiá, are quite vertical and very closely fitting, and are longer, more symmetrical, and finer-grained than the columns of the outer portion seen from near the junction just mentioned along the water-course, radiating in a north and north-eastern direction. The latter appear to have been also inclined to the north-west, but have been cut through and removed by the river, thus laying bare the central vertical ones. These are from 9 to 11 feet in length, and generally more or less distinctly though irregularly hexagonal, the disposition of the edges in two specimens being as follows :—

	I.	I.		I.	II.
1	4″	10″	4	1′1″	1′
2	11″	9″	5	1′3″	1′
3	1′	11″	6	1′4″	1′5″

The columns are marked very regularly with horizontal striæ, about an inch apart, and radiating fine striæ pass from a rather well-defined central "nucleus" to the border, which is about an inch broad, and being brownish through decomposition, is clearly differentiated from the body of the column.

Dangerfield noted the occurrence of basaltic columns along the whole bed of the Chambal, on the Malwa scarp and between Mandlesar and Mahesar.[1] Fraser also notices them.[2] The Mahesar columns which I had occasion to see on my way from Barwái to Mándu are not quite so long as some of the inner Mángdi columns; they agree, however, in

[1] Malcolm. C. Ind., Vol. II, pp. 323 and 329.
[2] Geol. Trans., Ser. 2, Vol. I, p. 156.

verticality and form. The Koteda columns near Gujri[1] agree in their radiation with the outer columns at Mángdi.[2]

Flora.—The trap is overlaid by soil of some thickness, only where it lies within the influence of streams and water-courses. The low and generally flat-topped trap hills nearer Mándu are covered with thin forests of Sálai (*Boswellia thurifera*), the dull monotony of which is broken chiefly by the sparse interspersion of Parása (*Butea frondosa*), Baer (*Ziziphus jujuba*), Ágola (*Phyllanthus emblica*), and a diminutive variety of Ság (*Tectona grandis*). In the Uri valley and further west, the Anjana[3] (*Hardwickia binata*) with elegant little green leaves entirely replaces the Sálai as the predominant trap-plant, and the Parása[4] is much more largely represented, so that the trap scenery of the western portion of the area comprised in this report presents a marked and agreeable contrast to that of the eastern.

Relations to underlying beds.—The relation of the trap to the subjacent beds is one of unconformity more or less marked according to the remoteness in age of the latter.

In the northern portion of the Mán valley, enclosed between two spurs of the Vindhyan range, the relation of the trap to the underlying beds affords a good illustration of the fact so clearly pointed out by Mr. Blanford,[5] *viz.*, that the cretaceous beds had suffered considerable sub-aerial denudation before the outpouring of the trap upon their surface. At Nimkherá, a good thickness of the typical coralline limestone was seen in the bed of the river, as well as just below the village; and some 2 miles westward, at Goári, a few feet of the nodular limestone are exposed. Proceeding still further west, the trap is seen to

[1] "Memoirs," VI, pt., 3, p. 130, and "Manual," p. 303.

[2] Columnar structure in the Deccan area is minutely described by Sykes (Geol. Trans., Ser. 2, Vol. IV, pp. 415, &c.).

[3] Some of the villages in the Uri valley are called after this tree: Anjantár (mis-spelt Ajantár in the Topographical Survey Map), Anjankhera, &c.

[4] This plant would be largely available for economical purposes (see Roxb. Flora Ind., Clarke's Ed., p. 540; Carey's Ed. III, pp. 244—247). But hardly any use of it is made in the district, where the people are evidently ignorant of its utility.

[5] "Memoir," Vol. VI, 3, pp. 51, &c.; Vol. VI, 2, p. 21; "Manual," p. 324.

rest upon metamorphics; patches of the coralline limestone, however, too insignificant to be mapped, crop out here and there along the southern bank of the river. And opposite Káchåoda this limestone is seen, with its thickness and extent considerably increased, to pass under the trap, east of a stream which passes by Deoli. But immediately south and west of that stream, for nearly half a mile, along both sides of the Mán, the basaltic series immediately overlie the metamorphic. Between Káchåoda and Ghursul, the pre-trappean cretaceous surface is extremely irregular. Immediately south, north, and east of Ghursul, however, perfect regularity prevails—the metamorphics, sandstones, limestones, and trap, succeeding each other in stratigraphical order.

The metamorphics were distinctly seen below the trap at Tándá. But beyond a mile or two of that town in every direction, except the northern (not examined), calcareous and arenaceous strata (usually not more than 5 to 10 feet in thickness) intervene at places very little apart. The interposition becomes more and more constant southwards, until, as at Anjantár, Iskiápura, &c., the presence of pre-Lameta cretaceous limestone is invariably noticed wherever the base of the trap is exposed. In the neighbourhood of Bág, to its east, as at Deodhá, the trap rests directly upon Nimár sandstone, but within a mile or two southward, upon coralline limestone. West and north-west of Bág the trap usually rests upon the Lametas.

Inter-trappeans.—The inter-trappeans near Punássá have been already alluded to. The fossils yielded by them are mainly *Cypris* and *Physa*. Near Barwái, at Rupabari, the latter genus occurs almost exclusively. The shells at the top of the inter-trappean limestone, *i. e.*, close to its junction with the trap, are considerably flattened. Small patches of the limestone occur near Gujri and Dharampuri. Here more than one species of *Unio* occur along with *Physa prinsepii*.

The inter-trappeans are nowhere of any great thickness—10 feet would be the average; nor do they ever extend far; and they invariably occur in the valley towards the base of the trap series. None but fresh-water fossils have been met with in the area surveyed.

CHAPTER X.

ECONOMIC GEOLOGY.

Iron.—Iron smelting has been the chief industry of the area under description. Heaps of slags are to be seen at most of the villages from near Hándiá to Barwái, and lower down the valley from Bág to beyond Káwant. The Dhár forest (Nimánpur district) and the Kátkut jungles, now all but depopulated, must at one time have carried on a brisk trade in iron. The furnaces near Chándgarh were given up only a few years ago, when the neighbouring forest came under the management of the Forest Department, and in the whole area the industry is kept up at present—and that, too, very feebly—only in the thickly-wooded country south of Satwás belonging to His Highness the Maharájá Holkár. An attempt was made by the British Government more than twenty years ago to revive the industry on a large scale at Barwái, now within easy access by rail from Khándwá on the Great Indian Peninsula Railway. But when the necessary preliminary arrangements had been completed under the superintendence of Mr. Mitander, an able Swedish metallurgist, the Government thought it advisable to have no further connection with the manufacture, and offered it for sale.[1] It was bought up by Holkár, but has never been worked; nor does there seem to be any prospect of its ever being worked.

The ore which is almost invariably hæmatite occurs at the following places:—

I. Hoshangabad district west of Hándiá, and north-west of Hardá (Map No. 1)—

(*a*) Kajberi (Kujberie) (lat. 22° 22′, long. 76° 59′). The ore is in the Bijáwar breccia, close to the boundary line

[1] See "Manual," Vol. III, pp. 397, 398.

separating it from the metamorphics; the pits sunk for its extraction are shallow, 6 to 8 feet deep.[1]

(*b*) Nimkherá (Lemekaira of Blackwell). The ore is similar to that of Barwái, and is in the Bijáwars. The place was not visited.

(*c*) Between Khudia and Mohla (lat. 22° 15′, long. 76° 47′). In Bijáwar breccia, pits deeper than usual, 50 feet.

(*d*) Basnia (deserted), 3 miles east of the Chhota Tawa. The ore occurs as superficial deposit.

(*e*) East of the Chhota Tawa, as a vein *in situ*, close to the ruins of Kotra (near Bará Bijalpur; lat. 22° 13′, long. 76° 40′).[2] Junction of the Bijáwar and Vindhyan sandstones. Pits shallow (10 feet deep).

II. Nimár district (Map No. 1)—

(*a*) A mile south of Dhárikotrá in the Punássá reserved forest, 8 miles east of Punássá[3] (lat. 22° 13′, long. 76° 35′). In Vindhyans as surface accumulation. Pits shallow. The ore was found too poor to make extraction remunerative.

(*b*) South of the Narbadá (1½ miles east of Billorá, lat. 22° 85′, long. 76° 9′). The ore occurs in the planes of foliation of metamorphic schists. It has never been worked, being too poor both in quantity and quality to be workable with profit.

III.—Nimáwar district (Holkár)—

(*a*) Between Báin[3] and Sendráni (between lat. 22° 26′ and

[1] Mr. G. J. Nicholls, C. S. (Records, Vol. XII, p. 173), speaks of an iron mine "2½ miles from Sontalai, near the Máchak river." Kajberi is at the same distance from Sontalai, but is on the Anjan. The mines alluded to are probably different. Mr. H. B. Medlicott identifies them with those of Karanpura. The neighbourhood of Sontalai received only a very cursory examination from me. I was informed by the people that the Kajberi mines were the only ones they knew of. The mine referred to is probably the same as that of "Kirmin" visited by Blackwell.

[2] Mentioned by Dr. Oldham, "Memoirs," Vol. II, p. 272.

[3] Bain must be the "Bawha" of Dr. Oldham, *op. cit.*, p. 271. It is now a very flourishing village.

22° 28′, and between long. 76° 42′ and 76° 44′). The ore is abundant and rich. It occurs in hollows as surface accumulations, chiefly close to the boundary between the Bijáwar breccia and Vindhyan sandstones. It is still worked by Kurkus for furnaces at Báin, Sendráni, Surmania (a new village 4 miles west of Sendráni), &c. The iron turned out is of good quality, but expensive.

IV.—Chándgarh district (Thákur of Chándgarh and British territory).—

(*a*) Mátni[1] (lat. 22° 16′, long. 76° 39′). The ore is very rich, and occurs close to the boundary of the Bijáwar breccia and Vindhyan sandstones. The mines supplied the neighbouring country north as well as south of the Narbadá. The pits examined were shallow, but, as in all such cases, they must have been partially filled up since they were given up.

(*b*) A mile west of Chándgarh (lat. 22° 15′, long. 76° 41′). The ore here occupies the unusual position of the top of a hill made up of Bijáwars. Here, too, the pits are close to the base of the Vindhyan sandstones; and the ore appears to be a surface deposit. It is rather poor.

(*c*) Nandana near Pamákheri (lat. 22° 20′, long. 76° 43′). The ore is in Bijáwar breccia. It is poor, and does not seem to have been much in demand.

V.—Nimánpur district (Dhár)—

(*a*) North-east of Bháurikherá (lat. 20° 22′, long. 76° 27′). The ore is very rich, and occurs close to the fault-line between the Vindhyans and Bijáwars.

(*b*) South-east of Jhirpániá (lat. 22° 29′, long. 76° 24′). Surface deposits in the Bijáwars.

[1] Mentioned by Dr. Oldham, Memoir, Vol. II, p. 272, &c.

VI.—Kátkut[1] and Barwái (Holkar)—

(*a*) Deserted village of Mendikhaira (lat. 22° 22′, long. 76° 14′). The mines in the neighbourhood are numerous, and much deeper than usual (25 to 50 feet). They are like the Bháurikherá mines along the fault-line bringing the Vindhyan sandstones against the Bijáwars.

(*b*) Andharibág (deserted), (lat. 20° 23′, long. 76° 14′). The pits here are deep and numerous.

(*c*) Chiktimodri.[2] The ore (which is among the richest in the whole country) was discovered by Mr. Mitander, the Swedish metallurgist in charge of the now defunct Barwái works, and the place where it occurs was in consequence named Mitanderpur. The ore occurs in a valley among metamorphosed rocks, which in the map are coloured as metamorphics, but may be Bijáwars.

(*d*) Karondia[3] (4 miles north of Barwai). In the Bijáwars.

(*e*) The mines at Nándniá, from which a large quantity of ore was raised for the Barwái works, are in Bijáwar breccia. They are deep, and were partially filled with water when I visited them late in October last year (1882).

(*f*) Karanpura (deserted).[3]

VII.—Bág (Sindhia)—

The mines of Bág have long been celebrated. They are, as usual, in the Bijáwar formation, and were worked to depths not less than 50 feet.

VIII.—Áli Rájpur district (Rájput chief)—

(*a*) West of Indwan by the Hátni (lat. 22° 17′, long. 74°

[1] Misspelt "Kandicote" in "Manual," Vol. III, p. 397.

[2] Misspelt "Chuti Modri" in Manual, Vol. III, p. 398.

[3] Mentioned by Blackwell. Selections from the Records of the Bombay Government, Vol. XLIV, p. 8. I could not identify Karanpura.

38′). The ore seems to be like that of Chiktimodri, and is also in the metamorphics.

IX.—Káwant (Chhota Udepur State)—

(*a*) Near Mohan. The ore (hæmatite) here occurs in the Nimár sandstone. It must have been worked, as quantities of slags lie about the place. It occurs as a bed of but limited extent.

As to the history of the working of these mines, there is but little handed down by tradition, and still less is preserved on record. The allusion to the steel mines of "Indore" in the Ãin-i-Akberi has been referred to in the Economic Geology of India[1] as proving their antiquity. But this Indore must have been quite a different place from the modern capital of Holkár, being mentioned by Abul Fazl as occurring in the subah of Berar,[2] and not in that of Malwa.

The well-known city of that name was quite an insignificant village when the Ain-i-Akberi was written (end of the sixteenth century), and it was only about the close of the eighteenth century that Ahalya Bai, pleased with its site, had a new city built near it, and ordered the head office of the district to be removed to it from Kampel (Malcolm's C. I., Vol. I, page 11). It is unlikely that the iron mines near Kátkut and Barwái should have been called after an unimportant village at a distance of 35 miles.

What trustworthy historical evidence we possess does not date back any earlier than 1800. In that year we have it on the authority of Sir J. Malcolm and Hamilton, that there were fifty iron-smelting furnaces at work at Kátkut. But in 1820 the number was reduced to two.[3]

In 1818, Captain Dangerfield noticed at Bág three smelting furnaces and as many forges employing 24 blacksmiths. The iron turned out is described by him to be of indifferent quality, owing chiefly to the "imperfect fusion and forging of the metal."[4] The furnaces were then

[1] *Loc. cit.*, p. 397.
[2] Ain-i-Akberi (Gladwin's Translation), Vol. II, p. 59.
[3] "Central India," Vol. II, p. 500.
[4] Trans. Lit. Soc., Bomb., Vol. II, p. 194.

worked for only three or four months in the year; and they ceased to exist about 1838.[1]

In 1856, the number of small country furnaces in the eastern portion of the area included in this memoir was estimated by Dr. Oldham at forty.[2] At present there are only half a dozen, south and south-west of Satwás, at Báin, Sendráni, and Surmaniá (a new village 6 miles west of Sendráni), all in Holkár's territory.

Lead and silver.—The "Chándi Khan," or silver mines, of Jugá, in the district of Hoshangabad, are locally well known. They were visited in 1855 by Mr. H. B. Medlicott, who found the deposit so thoroughly worked out that he had difficulty in ascertaining what the ore was. Some excavations were made there by Mr. G. J. Nicholls. The specimens forwarded by him were found on analysis by Mr. Mallet, Curator of the Geological Museum, to be useless as an ore, although "indicating the possibility of galena occurring in larger quantity." He found the lead extracted from the galena to contain 21 ounces of silver to the ton.[3]

Copper.—In the district of Nimáwar (Holkár), at a village called Tamkhân (lat. 22° 27′, long. 76° 54), I met with heaps of slags from copper furnaces. There is a line of shallow excavations at the place, and the ore probably occurred as a vein in the metamorphics. But it has been worked out; and I could not find any trace of it. I may remark that the name of the village signifies "copper mine."

I heard also of copper mines near A'li Rájpur. But the ground was not examined.

Lime.—Numerous pits are worked in the Bijáwar limestone for lime. The lime quarries near Barwái and at Barjar yield a very superior article, which is taken by rail to as far north as Oujein. In the Mán valley and further west, I saw a few lime-pits in the nodular

[1] Journ. As. Soc. Beng. for 1858, p. 119.

[2] Appendix to "Memoirs," Vol. II, pp. 271, &c. Dr. Oldham discusses in it, in detail, the probable cost of working the ores, the supply of fuel in the district, and other allied questions.

[3] See "Records," Vol. XI, pp. 173, 175.

limestone of the upper cretaceous series—at Oriá (south of Ghursul), Áspura (south of Bág), &c. Alluvial *kankar* is, however, the principal source of supply.

Building stones.—The building stones are good and varied.

1. Metamorphics.—The black limestone near Nimkherá on the Mán is largely quarried and taken to Dhár. It seems to have been in requisition at Mándu also.

2. Bijáwars.—These, as a rule, do not yield good building stones. At Chirákhán, 4½ miles west-by-north of Jugá, in the district of Hoshangabad, there is a sandstone which has been extensively quarried for the fort of Jugá, which stands in an island in the Narbadá opposite the village, as well as for temples in the neighbourhood. Being coarse and hard, it is but little prized.

The limestone, when not chert-banded, may be, and has been, employed, as for some temples at Khudiá (7 miles south-east of Chánd-garh). But it is usually too hard to be worked with ease.

Some of the Bijáwar slates, as near Bág, may be utilised for roofing and other purposes.

3. Vindhyans.—These sandstones have been largely used, though for comparatively rude constructions. They are well fitted for substantial structures, but not for ornamental work.

4. Gondwana sandstone.—The sandstones near Barwái and Kátkut have (with the exception of the coralline limestone) yielded the finest building stones of the district. The places where there are, or have been, quarries are—

1. Ghátiá and Rupabari (near Barwái).
2. Kátkut (3 miles east of it).
3. Bed of the Sukli river at Chandupura, north of Kátkut.
4. Áhkund.

The Ghátiá and Kátkut quarries were till lately worked for the Rajputana-Malwa Railway, especially for the viaduct at Mortakká. The stones for the new palace of the Bala Saheb at Indore are now largely obtained from the former. The Kátkut quarries have been given up. These appear to be the oldest, the now ruined forts and

temples of Mándháta having been mainly built of sandstone got from there.[1]

The sandstone is durable and soft enough to be carved with facility. There is a pretty little temple at Chandupara in which there is an inscription bearing date Sambat 1282, *i. e.*, A. D. 1255, so that it is 628 years old. But it appears as if it had been recently raised; and the carved figures look as if they were fresh from the chisel. The ruins on Mándháta hill offer instructive and interesting examples of the durability of the rock and its capability for elaborate carving. Richly carved pillars, some 14 feet high and 3 feet square at the base, and carved elephants, between 4 and 5 feet in height, in almost complete relief on stone slabs, and "executed with singular correctness and excellence of attitude," may be mentioned as instances.[2] Unfortunately the exact date of the temples and fort is not known.[3] But they cannot be less than 900 years old.[4]

The Áhkund rock was quarried for the fort and temples of Punássá and its neighbourhood. It was also partly employed for the viaduct on the Narbadá.

5. *Nimár sandstone.*—The lower massive beds of this formation yield good building stone. It has, however, been but little utilised.

6. *Coralline limestone.*—This is the best building stone of the country, whether we take beauty or durability into consideration. It takes a fine polish, and the thick clusters of branching Bryozoa, of which it is largely made up, give it a most picturesque appearance.

[1] I inferred this from the blocks of the rock lying on the way from Kátkut to Mándháta. But a portion of the material may have been obtained from Rupabaria, which is nearer. Captain Forsyth, in an article on Mándhatá in the *Central Provinces Gazetteer* (p. 259), says: The rock was "brought from a great distance," but does not suggest from where. The people of the place could not give me any information on the matter. But I have very little doubt that it was mainly broughtfrom Kátkut.

[2] For a fuller description see the article on Mándháta—*Central Provinces Gazetteer*, pp. 259 to 264. The Jaina temples north of the river have also sandstone as the principal rock.

[3] In the temple of Siddheswara, the finest now existing, I found an inscription which, unfortunately, for want of adequate help, I could not decipher.

[4] See Forsyth, *op. cit.*, p. 258.

Its employment in the temples of Omkárji[1] and Somnáth at Mándhátá, in the far-famed mosques and palaces of Mándu, and numerous other structures of less note, testifies to the exquisite taste of Indian architects in days long since gone by.

There is an outcrop of coralline limestone west of Barwái. But it is rather coarse and thin-bedded, and has to all appearance never been worked to any extent. When I visited the place last, however, about the end of March (1883), pits had been dug into it, and quantities of rock raised for the Bala Saheb's palace at Indore.

The old quarries were at Bowárla, Kherwán, and Chirákhán, west of Mándu, especially the last-named place.[2]

7. *Lametas.*—The Lameta limestones at places yield easily cut blocks.

8. *The Deccan Trap.*—This formation yields the commonest building stones. The fine-grained varieties of compact basalt are esteemed the best.

[1] The pillars are made of this rock. The temple, which is now called Omkarji, and attracts thousands of pilgrims from long distances, is a comparatively recent structure, The old temple must have stood on the top of the hill. But the materials of the new one have been derived from it. Modern Mándhátá is altogether a recent town—a monument of vandalism—the stones for its palace and temples being taken from the ruins of the ancient city on top of the hill. The practice of spoliation still continues, though on a much diminished scale, and should be put a stop to.

[2] The coralline limestone employed in the temples at Mándhátá was probably brought from Chirákhán, a distance of some 75 miles. The rock at Agarwárá, near Barwái, though much nearer, could not have furnished such good blocks.

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EXPLANATION OF PLATE.

Fig. 1. Slice of Deccan-Trap basalt with olivine from Kánpur near Áli, Áli-Rájpur State. (See p. 52.)

Fig. 2. Slice of dolerite from dyke of Deccan-Trap age in the bed of the Narbadá at Mandlesar, near Mahesar. (See p. 54.)

p = plagioclastic felspar.
o = olivine.
a = augite.
m = magnetite.

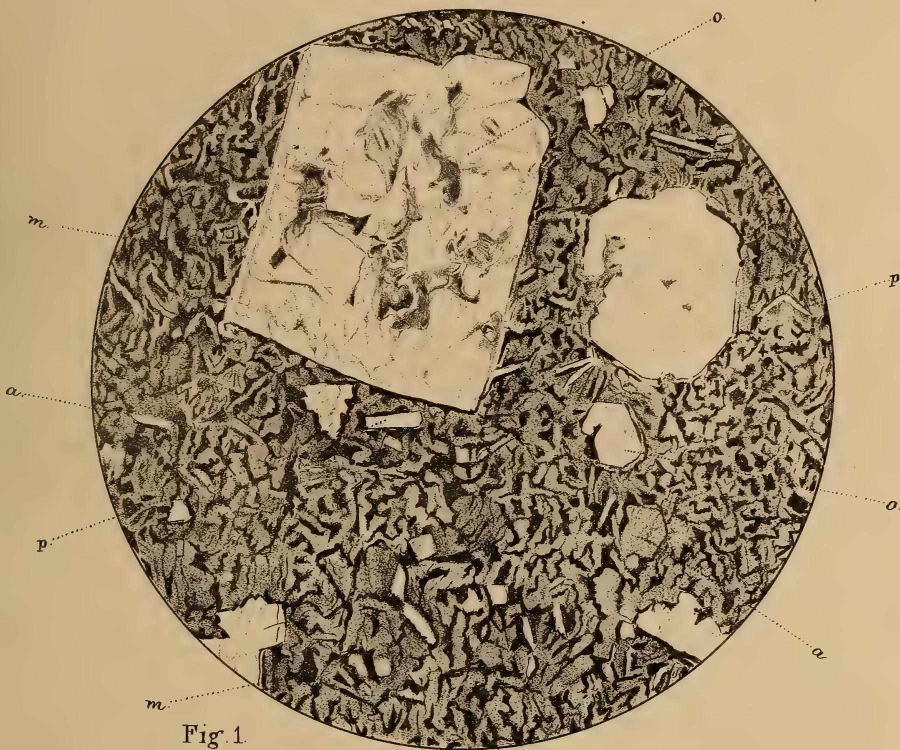
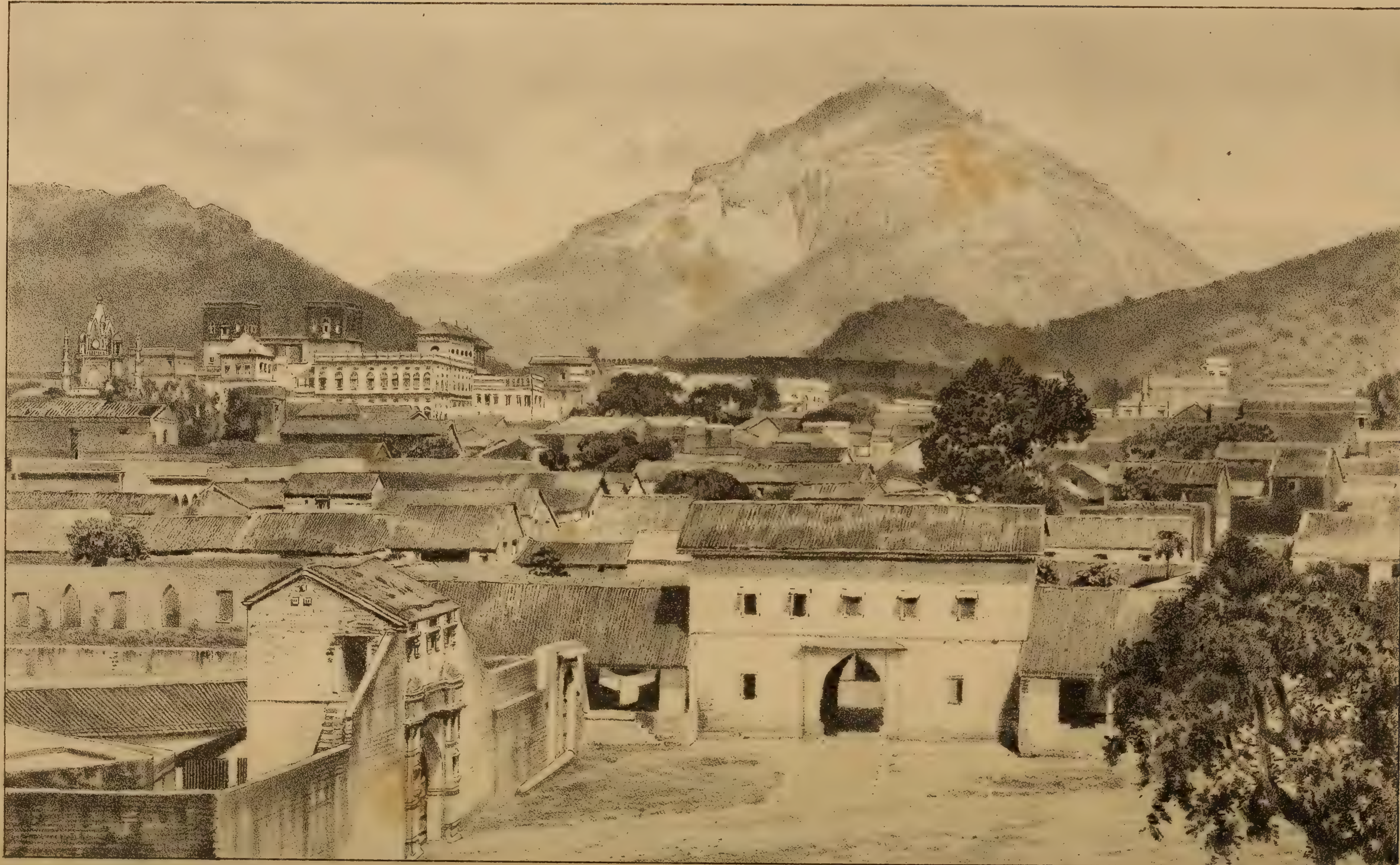


Fig. 1.

Fig. 2.

J. Schaumburg, Lith^a. Printed at Geol: Survey Office.



J. Schaumburg, Lith^d.

Junágarh. *with the* Girnār Hill *in the distance.*

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

VOLUME XXI, PART 2.

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MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

PREFACE.

It is desirable, or indeed needful, to indicate some points of correlation in the following memoir that are not quite up to date of our information. Only the paged proofs of the paper came into my hands on my return from Europe, and after Mr. Fedden had himself gone on furlough, so I could only introduce small verbal corrections.

In the table of formations on page 6, Mr. Fedden affiliates his Trappean-grits of Káthiáwár to the Infra-trappean-grits of Cutch, and his Wadhwán-sandstones of Káthiáwár to the Infra-trappeans of India. This latter term has always been restricted as synonymous with the Lameta group (Manual, page xiv, *et passim*), and although Mr. Blanford in his cursory survey of the Narbada region (in 1864) suggested that the cretaceous beds of Bág (Bagh) were probably on the same horizon as the Lameta group, the two have never been confounded, the latter being fresh-water deposits and the former marine. Mr. Bose in his recent detailed survey of the Bág region has further established the separation by tracing the distinctive Lameta beds overlying the marine beds of Bág. Now, it is plain from Mr. Fedden's description of the Wadhwán-sandstones (page 12 *et seq.*) that their affinity is with the Bág beds and not with the Infra-trappeans, or Lametas; the fossil contents, the stratigraphical relation of decided erosion-unconformity to the overlying trap, and the close connection with the underlying Umia sandstone, can

scarcely leave a doubt upon this point. It is only right to mention that Mr. Fedden seems not to have had access to Mr. Bose's memoir, the publication of which had been much delayed for the preparation of one of the maps; but the position was sufficiently clear from previous publications.

Although these main facts would seem to settle the correlation, there are some noteworthy discrepancies in details. The Wadhwán group is mostly sandstone, whereas the Bág beds are principally limestone. The cherty bands at top would recall a Lameta character of the Bág area. But the chief point of contrast with Bág beds is the association of trap rock with the upper beds of the Wadhwán group. This is implied in several places and is directly affirmed on page 18, notwithstanding the previously described deep erosion-unconformity with the trap. It may be that some of these cases are only contact-effects; and that in others, beds have been taken as of the Wadhwán group which should have been placed in the succeeding Trappean-grits.

Some vernacular words are quite needlessly introduced in Mr. Fedden's text. Foreign readers may like to know that *nala* means a stream, or rather its channel; *talao* is a tank; and *talaori*, I imagine, a little tank, or perhaps a pond.

The description of the sequence of formations in Káthiáwár seems to me to necessitate a correction of the sequence in the lower Narbada area as described by Mr. Bose in the first part of this volume, regarding the affiliation of his Nimár-sandstone, ranked by him as lower-cretaceous. The probabilities were already decidedly against this view (see Manual, page 221), and he has shown no sufficient ground for disregarding them. In the original cursory survey of that ground by Mr.

Blanford (*supra*, Vol. VI, part 3), this Nimár-sandstone (excepting only the oyster-bed at top) was included with the rock described by Mr. Bose as Gondwána sandstone, both being classed with the Bág-beds as cretaceous. The probabilities aforesaid were not then in view. In 1875 (Records, G. S. I., VII, page 73) a strong unconformity of the Bág marine fossiliferous beds to the underlying sandstones of Ghatia at the eastern end of the area were brought to notice, and the decided affinity of these latter with the upper Gondwána pointed out. After the correlation by Dr. Feistmantel of the flora of the jurassic Umia group of Cutch with that of the topmost group (Jabalpur) of the Gondwána system in the Sátpura region, the absence of any rock in Cutch between the Umia group and the thin zone of marine cretaceous deposits, to represent the mass of supposed cretaceous sandstone in the lower Narbada region, was noteworthy as confirming the view of these latter being really of Gondwána (Umia) age. From Mr. Bose's own description the same view is further confirmed. He did not, it is true, detect any other case of unconformity of the oyster-bed with the underlying sandstone, but the distribution of the two is conspicuously distinct, the latter occurring far and wide apart from the marine beds, while the oyster-bed is only noticed with the other marine beds, and is described as passing into them (*l. c.*, page 33). Moreover, the Nimár-sandstone is described as having a strong resemblance to the Gondwána beds of Ghatia, and as containing the same fossil drift-wood (pp. 32-35). And now the Káthiáwár evidence comes in: in comparative proximity to the lower Narbada region, and directly in extension of it, we find a small group fairly representing the marine cretaceous beds of Bág and resting directly on the

Umia. There seems to me very little room for doubt that the Nimár-sandstone is of upper Gondwána age, and therefore jurassic, not cretaceous. The probabilities of the case were duly pointed out to Mr. Bose, but as he had been over the ground and I had not, I did not insist. He seems to have been fascinated with the idea of making up a symmetrical cretaceous system—a fatal proclivity that is apparent in other parts of his memoir.

H. B. MEDLICOTT,
Superintendent, Geological Survey.

CONTENTS.

CHAPTER I.

INTRODUCTORY.

CHAPTER II.

GEOLOGY.

One plate and three maps.

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

THE GEOLOGY OF THE KÁTHIÁWÁR PENINSULA IN GUZERAT, *by* FRANCIS FEDDEN, A.R.S.M., F.G.S., *Geological Survey of India.* (*With a plate and a map.*)

CHAPTER I.

INTRODUCTORY.

Topographical.—The province of Káthiáwár (Kattywar)[1] occupies the peninsula between the Gulfs of Cutch and of Cambay in the Bombay Presidency. On the north it is bounded by the Gulf and Ran[2] of Cutch; while the extensive southern shore is washed by the Arabian sea. The extreme length of the peninsula is about 220 miles; its greatest breadth about 165 miles; and its area 22,000 square miles exclusive of any part of the Ran.

The peninsula has an irregularly shaped outline, somewhat resembling on a small scale that of a hatchet-head. Generally speaking, the surface is undulating with low ill-defined ranges of hills. The central

[1] *Suráshtra* was the old name for this portion of Guzerat. It was known to the Moguls as '*Soráth*', and to the Greeks under the name of Σαυραστρήνη.

[2] Sometimes spelled 'Runn' and 'Rann,' occasionally 'Erun;' the word signifies a waste tract dangerous to travel.

portion of the country is the most elevated, while the surrounding land, subsiding into extensive plains, has a general easy slope towards the margin of the peninsula.

The shores are, for the most part, very slightly raised above the level of the sea: along the south-east coast there are low cliffs here and there, formed chiefly of sub-recent rock; while the south-west coast presents a remarkably straight and unbroken line, fringed by low parallel ridges of consolidated shore deposits and sandhills. The northern and eastern confines of the province are the least conspicuous; the rock plains merging, on the one hand, into the shallow Gulf of Cutch without definite coast line, and on the other, into the great stretch of alluvium towards Ahmedabad. Sandhills are prevalent along a portion of the margin of the Ran.

Hills.

With the exception of the Tángha and Mándháv hills in the west of Jhaláwár, and some unimportant elevations in Hallár, the northern portion of the province is flat; but in the southern part beyond the central tract of broken hilly country, in which are some great mural scarps, there are several prominent ranges and detached hills. Of these, the Junágarh group is the most conspicuous, with its lofty peak, Gírnár, rising to a height of 3,666 feet above sea-level. A short distance to the south-east of this group begins the 'Gir' (or Gar) range, a hilly jungle tract, which stretches away for 20 or 30 miles in an easterly direction. A rather sharp anticlinal fold in the rocks south of Bhávnagar (Bhownagar of the Map) has been named the Khokhra range. Shetrúnja,[1] or the sacred hill of Pálitána, lies 18 miles to the west of the Khokhra range.

Returning westward, we have the Barda[2] group, an assemblage of hills, covering an area of about 70 square miles, to the north-east of Porbandar. Osham is also a conspicuous hill, rising abruptly from the plains west of Junágarh.

Several of these hills are volcanic, or at least had an eruptive origin, as will be demonstrated from their structure in a later chapter. Another

[1] Often written 'Satrúnja.'
[2] More correctly 'Baradá,' as in Hunter's Gazetteer.

feature to be noted about the hills, considering their inland position, is that in many instances their seaward sides are the steeper and often precipitous, while the other sides tail off more gradually, or die down into broken ground. There is a remarkable feature in the topography of the Gohelwár division of the south-eastern part of the province; namely, the occurrence of numerous narrow ridges running for many miles across the country, like long embankments, or at times resembling great ruined walls. These often continue parallel to each other for long distances, while others cross them nearly at right angles; and they frequently attain a height of 200 or 300 feet above the plain. The same feature is noticeable, though less conspicuously, in other parts of the country.

Rivers.

The drainage of the province, as might be inferred from its configuration, is distributed on all sides over a great number of small river areas. Of these the following are the more important. In the northern division we have the Áji passing by Rájkot; the Machu by Wánkáner, Morvi, and Mália; and the Bhámban, which discharges into the 'Ran' near Tikar. In the south-west, one of the Bhádars[1] passing Jetpur and Kúntiyána to the sea at Navi-Bandar, runs a course of 120 miles: this is the largest river in the peninsula, and it is navigable for small boats up to Kúntiyána during the months of July, August, and September. The Ojat drains the Junágarh hills on every side, and diffuses its waters over the alluvial flats near the coast below Navi-Bandar.

In the eastern division: we have the two Bhogáwas, one passing by Múli and Wadhwán, the other by Limbri; the second Bhádar passing by Ránpur and Dhándúka; the Khalubhar, which is tidal at Bhávnagar; and the Shetrúnja passing Talája and falling into the Gulf of Cambay near Gopnáth Point. With the exception of the Bhádar first mentioned, these rivers can hardly be described as perennial.

Rainfall.

Though Káthiáwár is within the influence of the south-west monsoon, the rainfall is usually very light. The average annual fall at Rájkot is stated to be under 28

[1] There being two rivers having this name, as well as two Bhogáwas, it is necessary so to distinguish them.

inches. But the amount varies rather considerably in different parts of the province: at Gogha (Gogo) on the east coast, the rainfall is seldom more than 20 and often as little as 12 inches. The register at Bháv-nagar for ten years prior to 1878 shows an average of 26·35 inches per annum.

Soil and vegetable products.

The province is agriculturally wealthy; the soil, though not of extraordinary fertility, being generally of fair quality and amply watered. The principal vegetable products of the country are cotton[1] 'kapas' (*Gossypium herbaceum*), 'bajri' (*Penicillaria spicata*), and 'juwár' (*Sorghum vulgare*), and in some parts sugar-cane 'serdi' (*Saccharum officinarum*), wheat 'ghau' (*Triticum æstivum*), rice 'dangar' (*Oryza sativa*), gram 'chana' (*Cicer arietinum*), 'math' (*Phaseolus aconitifolius*), and oil seed 'tal' (*Sesamum indicum*).

Animals.

The wild animals include the lion (now found in the Gir range only, but formerly in the Barda hills also), panther, cheetah, nylgai, sámbar, antelope, gazelle, hog, hyena, wolf, jackal, lynx, wild cat, fox, porcupine, and other smaller vermin; while the crocodile is common in many of the streams.

Of birds, wild duck and game birds are plentiful in those parts of the country suited to them, together with numerous storks, cranes, and pelicans. The great Indian bustard (*Eupodotis edwardsi*, Gray) is occasionally met with on the plains.

Previous geological writers.—There is scarcely anything authentic on record regarding the geology of the peninsula itself: the little island of Piram (Perim), off the east coast, has however frequently received attention since the discovery in 1836 of quantities of fossil bones and wood on the reef surrounding the islet. The earliest announcement of this

Hügel.

discovery is given in a letter dated April 1836, by Baron Carl von Hügel to the Secretary of the Asiatic Society of Bengal, and published in the May number of the Society's Journal for that year. Baron Hügel states that Dr. Lush, who showed the first specimens to him, has the merit of the discovery. At

[1] The cotton annually exported supplies one-sixth of the total amount of cotton shipped from Bombay to foreign countries.

the same time, and in the same Journal, was published a description of the islet by Lieutenant Fulljames. In the December number of the volume, there are some 'geological notes' by Dr. Lush, which relate in part to the islet of Piram and neighbouring coast.

Falconer.

In 1845 Dr. Falconer read a paper before the British Association on some Piram fossils collected by Fulljames; and later in the same year he published, in the Quarterly Journal of the Geological Society of London, a fuller description of the Piram fossils, together with extracts from the papers above mentioned regarding the structure of the island and opposite coast.

Theobald.

In the year 1857, Mr. Theobald, late of the Geological Survey of India, examined a portion of the country bordering the southern and eastern coasts, but his report was not published, and therefore need not be taken in review. But since it was the authority for the statement in the 'Manual of the Geology of India' (p. 342), that nummulitic limestone occurs in Káthiáwár, I may here mention that no such rock has been met with by me in the province. None of the tertiary rocks exposed can be of earlier age than miocene.

It has been stated from time to time, in sundry reports and gazetteers, that the Girnár of the Junágarh hills is a mass of granite; this too is erroneous: the Girnár mountain is composed mostly of diorite (a black and white crystalline granular rock of hornblende and felspar) and of mica diorite. There is no granite in any part of the country.

Blanford.

In February 1863, Mr. W. T. Blanford made a visit to the island of Piram, and published a note on the subject at the end of his memoir[1] on the geology of Western India (issued, January 1869). The chief object of his visit being "for the purpose of endeavouring to ascertain if the beds there existing, which from their mammalian fauna are considered of miocene age by Falconer, presented any marked resemblance to the upper beds in the Oomrawattee, Keen, and Taptee rivers."

[1] Memoirs, Geol. Sur. India, Vol. VI, part 3, p. 211.

CHAPTER II.

GEOLOGY.

Geological formations.—The following table comprises all the formations occurring within the province. Several of them are but poorly represented, both in thickness and extent. The trappean series assumes by far the most prominent position, as it occupies fully two-thirds of the total area of the Káthiáwár peninsula, and its maximum thickness can scarcely be less than 3,500 feet. The tertiary rocks form a fringe to the trap along the southern limit of its area, but they are greatly obscured by the later sub-recent deposits and alluviums.

Table of geological formations occurring in Káthiáwár, in descending order:—

Formations.	Approximate geological position.
Alluvium. (Sand dunes, tidal flats, freshwater alluvium, 'ran' clays, raised beaches and miliolite.)	RECENT AND SUB-RECENT.
Dwárka beds.	? HIGHER TERTIARY, or POST-PLIOCENE.
Gáj beds.	UPPER MIOCENE.—(Lower Manchar in part, and Gáj of Sind.)
Lateritic rocks.	? LOWER EOCENE.—(Sub-nummulitic (*Wynne*) of Cutch, and ? High-level laterite of the Deccan.)
Traps.	CRETACEO-EOCENE.—(Deccan traps.)
Trappean grits.	? CRETACEOUS.—(Infra-Trappean grits (*Wynne*) of Cutch.)
Wadhwán sandstones.	? CRETACEOUS.—(Infra-Trappeans of India.)
Umia beds.	JURASSIC.—(Upper Gondwána.)

Umia beds.—The only representative in Káthiáwár of the great jurassic system is a group of sandstones exposed in the northern part of the province, and occupying an area of about one thousand square miles. These sandstones have been determined, by their mineral character and

by certain plant impressions, to belong to the Umia[1] group of Cutch. They do not represent the entire group, nor can their precise horizon in the group be stated; though—from the absence of the Cutch lower marine beds, and the identity of some of the plants with the Jabalpur group of the Gondwána system in the Central Provinces—the probabilities are that the Káthiáwár beds represent the upper division chiefly, and perhaps a higher development of the group than is seen in Cutch.

Sandstones and shales.

The sandstones are mostly open, imperfectly cemented, and unevenly stratified with coarse and gritty, or even conglomeratic, runs and layers. There are, however, some thick beds of fine texture among them, and a few subordinate bands of shale. Oblique lamination is very prevalent. Owing to the rocks in this field being so little disturbed from their original horizontality, and the country being generally flat, a natural section showing any great succession of beds cannot be expected. Thus, it is difficult to give an estimate of the thickness of the group; moreover, denudation has affected the surface, and the base is nowhere laid bare.

Thickness.

There may be an aggregate thickness of about 1,500 feet exposed; and this, perhaps, exceeds the actual amount, for, in some parts of the field, similar rock spreads over large areas.

In the following details, the relative positions of certain zones in the group are given as nearly as can be.

Harsh and conglomeratic beds.

The hills with rugged outline, occupying the more elevated parts of the central portion of the field, are formed of harsh sandstone, ferruginously stained to dark purple or black. The rock is very coarse in parts, and even conglomeratic with small pebbles of white quartz imbedded in a dark ferruginous matrix: occasionally it is free from iron, or faintly mottled red and white. In many places it is so compact as to resemble quartzite. In this state it is

[1] The term 'Umia' was instituted by the late Dr. Stoliczka to denote a great thickness of beds succeeding the 'Kátrol group' in the jurassic series of Cutch. With the exception of the plant-bearing strata, which are scarce, they are for the most part unfossiliferous, and probably of fresh-water origin: marine fossils, however, are said to occur in a band towards the base, and again in a bed near the top of the group. None of these marine fossils have been detected in the present field.

quarried for 'quernstones,' or handmills, for grinding corn. This harsh sandstone, with conglomerate, I consider one of the uppermost exposed members of the group.

Softer sandstones of the plains.

The rock below it—forming the base of the hills, and occupying the open country and wide-spreading plains—consists of yellow, and pale-coloured, soft sandstones, variable in texture, often speckled with kaolin, or decomposed felspar, and sometimes warted with calcareous concretions. The coarser parts frequently change to grit, and conglomeratic bands of cemented pebbles are met with. The bedding of this rock is ill-defined, but cross lamination is very prevalent and strongly marked, especially among the finer deposits. Wherever large surfaces of this sandstone are exposed and sufficiently clear, excellent examples of a kind of 'ripple mark,' or current wave, may be often seen, showing that the material of the rock was pushed along, when deposited by swiftly flowing shallow water. The oblique lamination presents large semicircular, concentric wavelets. A good illustration of this occurs in the broad flood-way of the stream course on the west side of the town of Thán. Here two distinct sets of wavelets can be traced, the one almost at right angles to the other.

The light-coloured soft sandstone is one of the most prevalent rocks in the field, but it is rarely sufficiently coherent to bear trimming to the size of a cabinet specimen,—a blow from the hammer shattering it to sand. The surface only becomes somewhat more compacted by percolation of lime, after long exposure to meteoric influences. This member of the group attains a considerable thickness, which cannot be far short of 500 feet in the hills situated between Chotila and Thán.

Ironstone band.

About the middle of the soft sandstone beds, or somewhat lower, is an ironstone band, varying in different parts of the field from a red clay-shale with layers of earthy red hæmatite, or bole, to a brick-red highly ferruginous sandstone.

Near Wánkáner, and again at Mátel, 9 miles to the northward, the band is strongly developed in red earthy and arenaceous beds. At Deosar, 6 miles north-by-east of Chotila, it is a purple-red shaly band

of about 12 to 15 feet in thickness, passing down into ferruginous sandstone. It is traceable for some distance along the scarp of the hills to the westward, but appears to thin off to the east: at Chorvira, in the latter direction, it is only a very few feet in thickness; and it is succeeded, above and below, by the light-coloured soft sandstone.

In former days this ferruginous band was worked, and the ore smelted for iron in many places, notably at the village of Kántrori, 8 miles west of Sara. Scarcity of fuel and the cheapness of the imported metal have caused this industry to die out.

Plant shales.

Among the sandstones below the ferruginous zone, there occurs a band of thinly-laminated fine shaly sandstone, or arenaceous shale, associated with dark argillaceous and carbonaceous shale, the latter containing numerous impressions, mostly fragmentary, of fossil plants, leaves, seeds, &c. The fossils were obtained from two localities—one near the village of Songadh 2½ miles N.N.E. of Thán, and the other three-quarters of a mile north-west of Thán. There is a very limited exposure of the beds at either place. The specimens from Songadh comprise, on the authority of Dr. Feistmantel the following:—

FILICES.

Pecopteris, sp.
Tæniopteris, sp.

CYCADEACEÆ.

Podozamites lanceolatus.

CONIFERÆ.

Echinostrobus (*Thuites*) *expansus*.

Of these plants, the last named is common to both the Jabalpur and the Umia (Cutch) groups; while the *Podozamites* was known in the former group only.

The second locality (north-west of Thán) proved the richer, and the specimens obtained therefrom have been named and discussed by Dr. Feistmantel in a short paper published in 1880.[1]

[1] Records, Geol. Sur. India, Vol. XIII, p. 62.

List of fossil plants from the locality north-west of Thán.

FILICES.

* *Alethapteris* (*Asplenium*) *whitbyensis*, Göpp.

CYCADEACEÆ.

Ptilophyllum cutchense, var. *minimum*.

CONIFERÆ.

Palissya jabalpurensis, Fstm.
Taxites tenerrimus, Fstm.
* *Araucarites cutchensis*, Fstm. (seeds).
? *Pinus* comp. *nordenskiöldi*.

The two plants indicated by an asterisk in the above list are known in the Jabalpur and the Umia (Cutch) groups. Two others, the *Palissya* and the *Taxites*, were hitherto unknown in Umia's beds. Dr. Feistmantel writes (*loc. cit.*): "A comparison of these fossil plants shows that they are related to the flora of the Jabalpur group by the presence of *Palissya jabalpurensis* and *Taxites tenerrimus*; while *Araucarites cutchensis* is common to the flora of the Umia and Jabalpur groups."

Carbonaceous shale.

The black carbonaceous shale at the fossil locality north-west of Thán exhibits strings and laminæ of coaly matter, but not in sufficient quantity to burn as a fuel; neither is there promise of any useful fuel being found in the field. The existence of this carbonaceous shale has given rise to the reiterated report that 'coal' had been discovered in Káthiáwár, but this is fallacious, the facts being as here stated.

Arenaceous shale is also exposed at Amárpur, 2 miles north of Thán; at Samtherwa, 6 miles south of Máthak, and near Maika 8 miles to the southward of Wánkáner. At the last-named locality the rock is mottled purple and white; it has a fine silty texture, and is very brittle. No fossils were obtained, nor was the black argillaceous and carbonaceous shale observed at any of these places.

In the north-eastern part of the field, the plant-bearing arenaceous

shale was met with in two or three places on the road from Dhrangadra to Wáori on the Phulka stream. About half way, some mottled pale grey and purplish finely arenaceous shale is exposed at a *talaori*, and here and there along the *nala* leading into the Phulka stream opposite Isadara. The rock contains many fragmentary impressions of plants, some of which look like seed-wings (*Araucarites?*). At the junction with the larger stream, the shale is more compact and strongly bedded, and has been quarried to a small extent. The prevailing rock in the neighbourhood is the usual harsh and gritty whitish sandstone, the shale occurring as an inlier.

At Kúwa, on the Godra stream, a light-coloured very fine shaly sandstone bearing a few indications of plants is seen on the north side of the village.

Exposures along the Ran.

An isolated patch of the Umia rocks occurs in the broad stretch of alluvium to the north of their main area. It extends for about 12 miles along the borders of the Ran; but is very much obscured by sandhills. The rocks are best seen in the eastern portion, about Handi Bet, where the scarped hills show a thickness of about 50 feet. The following beds were observed in descending order; their Cutch *facies* is at once recognizable :—

(*a*.)—Hard black ferruginous grit, occasionally coarsely gritty, with white and colourless quartz and a few jaspery pebbles. It passes down into a thick bed of rusty-brown coarse grit of colourless and white quartz in a sandy matrix. Some of the quartz grains are sub-angular, while the rest are fairly worn. This rock also contains small lumps of a chalky earth.

(*b*.)—Below this come very thick cross-bedded sandstones, softer and less ferruginous, but still stained, mottled or streaky, yellowish brown, or red, finely speckled with white. Some thin ferruginous bands assume a scabrous appearance when weathered.

(*c*.)—The lowest rock seen is a white coarse and gritty sandstone, of roughly worn transparent white and bluish quartz grains,

loosely held together by a scant calcareous paste. The bed shows strong oblique lamination.

The general lie of these beds is horizontal or nearly so: near the Mandarki *talao* they are locally tilted 10°—15° to south-south-east.

The white sandstone is again seen at an outlying knoll in the alluvial plain between the two villages of Ghántila. It is more or less kaolinic, with occasional lumps of white clay enclosed; the quartz is partly sub-angular and dull cloudy white in colour, or dark blue in the coarser parts.

The hillock is masked with gravel mostly of flints and agates derived from the traps, the larger pebbles of which have accumulated on the northern side.

Wadhwán Sandstones.—In the neighbourhood of Wadhwán Camp, and at other places along the edge of the traps, a set of sandstones is found overlying the Umia beds, but not decidedly separable from them.

The traps are very thin in the north-eastern division of the province, and their basal flows are seen to be strangely associated and tangled with the sedimentary beds below them. There are irregular accumulations of sandstone more or less impure, frequently unsorted in texture, and for the most part indifferently cemented, though sometimes indurated by local crush to hard rock resembling quartzite. Lumps of decomposed trap are occasionally seen imbedded in the sandstone.

Red sandstone with cherty bands.

The most prominent member of this group is a brick-red or dull reddish-brown sandstone, very prevalent in the vicinity of the Wadhwán civil station. This sandstone is fairly exposed in the river bank at and above the station. Here it displays local aggregations of small quartz pebbles, and also ferruginous nodules or galls; the bedding, which is very indistinct, does not indicate any displacement from its original horizontality.

Marine organic remains.

In the upper part of this exposure, there are cherty and chalcedonic segregations, some of large size, which appear to consist of matted accumulations of organisms now much obscured by the silicious infiltration. Small spiral shells can be seen

in section on a newly-fractured face, but they cannot be developed sufficiently for determination, and many minute Bryozoa may be detected with a lens. A piece of silicified wood was also obtained from the same locality. The nature of the rock gives it a strong resemblance to the cherty members of the Bág beds.

The base of this peculiar sandstone is not exposed in the Bhogáwa river section, nor is its relation to the underlying rocks clearly displayed anywhere. Its association with the traps is, however, very well seen in a ravine a mile or so to the west of the station, where the latter abuts against and partly overlaps the sandstone.

The same rock is exposed for a limited extent in the ravines on the north side of the town of Sitha, 10 miles north of Wadhwán station: but its association with the trap alongside is not so clearly seen as in the former locality. The thickness of the sandstone here, however, must be considerable, if the native testimony be true that a well was sunk to a depth of 50 cubits piercing no other kind of rock.

In the Morvi State to the westward, the Wadhwán sandstone is again seen, but very sparingly. The stream at Jhinkiáli, 12 miles north of Morvi, has exposed both the red and other sandstones of this possibly cretaceous group. In the right bank of the stream about 300 yards above the village, is a large boss or dome-shaped mass of brick-red softish sandstone, readily weathering and reticulated with calcite. This mass is nearly surrounded and overlapped by decomposing traps, as shown in the following sketch section:—

Sketch Section
α. Trap. β Sandstone

The stream bank at the village shows a section of 30 or 40 feet of various soft sandstones—yellow, red, and light-coloured, lying horizontally. Similar beds are again exposed, to the east of the village, in the

banks of a watercourse, where they are overlaid by the traps of the surface. The basal traps are, as usual, much decomposed, friable, and very various, and are associated and mingled in a confused manner with the sedimentary beds; some of the latter have even a trappean aspect; and it seems probable they were being deposited when the trappean epoch set in.

Inliers east of Morvi.

East of Morvi town the traps are very thin, and several small inliers are exposed of varying sandstones that I am disposed to regard as members of the present group. The red unsorted softish sandstone is prevalent, and associated with other light-coloured slightly calcareous sandstones, with some argillaceous bands. The inlier south of Ghotu is a tough compact, rather calcareous gritty sandstone. It is cross-bedded, and appears tilted four or five degrees to east-30°-south. A similar rock crops out below the trap scarp near Páneli, and may be traced nearly as far as Gidach. Umia sandstones occupy the low ground and plains. In the scarps of the two outlying trap-capped hills south of Páneli, red sandstones varying to orange or yellow, unsorted in texture and gritty, and slightly calcareous in part, form one-third of the hill-sides. At the southernmost of the two hills, the unsorted gritty sandstones are more massively bedded, and are seen to rest upon the somewhat uneven surface of the Umia sandstones of the plain.

Inliers south-west of Wadhwán.

Isolated hillocks of similar gritty slightly calcareous sandstones occur in the Wadhwán district, forming inliers, which protrude, as it were, from under the thin traps of the plain. The matrix of the sandstone is sometimes observed to be porcellaneous. The sandstones in the area between the two Bhogáwa rivers, are often locally disturbed, being tilted as much as 60°, or more, from the horizontal: and the rock occasionally presents the appearance of induration and crush where slickensides have been developed. The displacement, in some instances, appears to be merely superficial; as though the surface beds, while yet unconsolidated, had been ploughed up by the flowing lava—erupted through

long fissures, which are indicated by the very remarkable trap dykes to be described further on;—or otherwise disturbed by earthquakes and floods, that must have accompanied the ushering-in of the great trappean, or fissure-eruption period.

Marine limestone ? cretaceous.

A few Bryozoa, and indefinite organisms, can be detected in some of these beds, but they are not conspicuous. Among the disturbed rocks is occasionally observed a drab-coloured, tough, sometimes gritty and chalcedonic, organic limestone of marine origin. It is almost invariably displaced, and its relations with the associated rocks are very obscure. The fossils are chiefly Bryozoa in a matted mass of indefinite shells, (like *Natica*, and broken bivalves,) and a few small corals. One small Echinoderm and some spines were obtained, but too imperfect for identification, and a portion of a flattened keeled Ammonite, that in some respects can be compared to *Am. guadaloupæ*, Roem., a well-known cretaceous fossil.

The limestone, which varies from a few inches to about four feet in thickness, is seen in the stream section two miles north-west of Bháduka, also in the Bhogáwa river near the village; and again about a mile and a quarter south-east of the village, there are two small outcrops. In all these places it is displaced and in tumbled association with volcanic and other rocks. The limestone was also noticed two miles north-east of the Chotila dák bungalow, as a small patch between two little outlying trap hills. It is here only a very thin shaly band underlying the trap, and resting upon dark purplish-red coarse open sandstone, which is apparently an outlier of the Wadhwán beds, since it rests upon recognisable sandstones of the Umia group.

The rocks on the eastern flank of the trap hills four miles east-north-east of Chotila are very similar to those just described: there is the Wadhwán sandstone, enclosing masses of a strange rock (? volcanic), and a band of gritty limestone, a few inches only in thickness, associated with various nondescript shales and sands. The limestone contains many fragments of Bryozoa, and of shells, besides a few very small corals. It was from this locality that the small imper-

fect echinoid and spines were obtained. This bed is tilted at about 80°, to south-30°-west. The sandstones with which the band of gritty limestone is associated are also turned up at the same angle just at this spot. There is no clear section, and the rocks are confused.

At Bháduka the limestone is cherty, with small segregations running in the direction of the bedding; it is, as usual, tilted and displaced. There is here a still greater confusion among the rocks; traps are very various, including volcanic ash and agglomerate. A coarse unlaminated sandstone—evidently a rapid accumulation, as from floods—contains rounded masses of decomposed amygdaloid, and portions of other rock.

In the small *nala* on the south side of the high road east-south-east of Bháduka, the organic limestone is seen in thick masses tilted on end. The rock is somewhat silicious and very tough. It was from this locality that the flattened keeled ammonite was obtained, together with a small *Ostrea* and a crenulated *Natica* (*?*), besides some small corals. In the *talaori* at the head of the *nala*, there is a small outcrop of the limestone apparently dipping 5° south of east at 50°—60°, but no other rock is exposed there.

Near Sidsar, a village three miles north of Sáyla (Sáhilá) in the Wadhwán district, a few imperfect fossils (mostly fragments of an ostreoid shell) were obtained from a crumbling calcareous sandstone associated with impure limestone and various other thin bands. The whole extent of the exposure does not exceed a few yards, and they are covered up by traps close by.

Near the village of Timba, in the stream that passes by Khárwa, south of Wadhwán city, there is an instance of abnormal intercalation of sandy beds among the basal trap flows. Trap is seen both above and below these at this point of the section; but in other parts of the section, sedimentary beds are tilted at high angles, and the conditions appear abnormal, as though the margin of the latter had been turned up and imbedded by the trap flow.

Further down the stream there is, in the vicinity of Khárwa, quite a jumble of various and heterogeneous traps with sedimentary accumu-

lations, of very varied and nondescript character, much weathered and disintegrated, and covered with saline efflorescence. One of the traps has an agglomeratic appearance, the imbedded lumps and masses being dark and scoriaceous. These traps also disintegrate rapidly, and are impregnated with salt. In almost all places where the perturbed accumulations at the base of the traps are exposed, both the sandstones and the associated traps are intensely saline.

At Sejakpur and in the tributary stream to the north that, for some way, forms the boundary between the Sáyla and Sejakpur *taluks*, a similar jumble of rocks is seen at the base of the traps, and is further complicated by masses that appear to be intrusive. It is often impossible to determine from surface examination only, whether some of these decomposed and queer-looking traps are really intrusive, or merely displaced masses of volcanic rock. They are too irregular and ill-defined in shape and direction, to be regarded as dykes; moreover, most of the dyke trap is compact, whilst these masses are frequently amygdaloidal, yet differ much from the regular bedded traps.

These strange and complex rocks are, perhaps, best seen in the neighbourhood of Bháduka, and along the channel of the Bhogáwa river, as far as Godávari. At Shekhpur, a village a little lower down, a large open irrigation well shows the following section. At the top is basalt, then below comes an earthy chocolate-brown argillaceous rock with enclosed lumps of decomposed amygdaloidal trap. These lumps are sparingly scattered in the upper part, but become more abundant below, and towards the base constitute (together with other miscellaneous trap fragments) the bulk of the rock mass. The subjacent strata were not seen, but the agglomerate here is in all probability the bottom bed of the trappean series.

At the most southern limit of the sandstone area, in the south part of the Chotila district, a small but interesting section is exposed in the right bank of the stream passing Mewása, about a mile below the village. At this spot, the traps are seen to rest unevenly upon a bed of soft coarse sandstone, in which are imbedded lumps and fragments of trap; thus

showing that this bed was accumulated at, or immediately subsequent to, the beginning of the trappean outburst. The sandstone is gritty, and finely conglomeratic in part, though distinctly laminated; and the enclosed lumps of trap are scattered irregularly and sparingly, here and there, through it. The base of the bed is not exposed.

Trappean grits.—The laminated gritty and trap-like deposits, so strongly developed at the base of the traps in Cutch,[1] are but poorly represented in northern Káthiáwár, by an isolated thin patch or remnant, of about three square miles in extent, in the plain four miles to the north of Thán. The rock is identically the same as that in Cutch, having a yellowish or olive-green colour, and a decomposed trappean appearance. It is more or less sandy or gritty, with quartz grains, and has a laminated, or rather shaly structure. It was, doubtless, a volcanic product deposited in water along with sand.

Gritty volcanic rock near Abhepur.

On the south side of a low ridge of sandstone, running from Abhepur towards Thán, there is an isolated mound, or boss, of broken rock projecting above the cultivated soil. The weathered surface is dark, with a rough gnarled and scoriaceous appearance: internally, the rock has a light grey colour varying to shades of brown, and an agglomeratic (or at least heterogeneous) structure, and is gritty with quartz granules. It is undoubtedly of igneous origin, but the difficulty is to account for its isolated position,—supported, as it is, on ordinary light-coloured Umia sandstone, which is visible on three sides of the mound. It appears to occupy a hollow on the surface of the sandstones; the mound itself is not more than 20 yards in extent; there is no bedded trap in the neighbourhood. Another small exposure of similar rock occurs about a mile and a quarter to the south, among sandstones which are disturbed and slightly faulted with dykes, but its position here is not the less enigmatical.

The miscellaneous accumulations of earthy felstones, volcanic ash

[1] See Memoirs, Geol. Sur., India, Vol. IX, p. 56.

and agglomerates, occurring in many places at the base of the bedded traps, are probably about the same date as the trappean grits. They not unfrequently occupy hollows, or depressions, in the sandstone floor on which the traps are superimposed. In the vicinity of the village of Mewása, ten miles south of Chotila, various rocks—ashes, felsites, &c.—are seen filling irregular hollows of the Umia sandstones near the scarped margin of the trap area.

Some of the earthy felsitic rock, which is mostly in a decomposed state, is porphyritic with a white and pale-green soapy mineral; other parts have a brecciated, or agglomeratic appearance.

Traps.—In the foregoing section, I have treated mainly of the miscellaneous volcanic accumulations belonging to the inception of the great Deccan trap period; in the present section, we have to deal with the bedded trap-flows. The trap formation in Káthiáwár—un-

Bedded traps.

questionably an extension of that in Cutch on the one hand, and of those in Guzerat and Malwa on the other—stretches from the east coast at a point below Gogha, to the western shore, where it sinks below the Gulf of Cutch. It prevails to within a few miles of the southern coast, where it is overlapped by tertiary and post-tertiary deposits. North of Bhávnagar it is covered by alluvium. In the northern division of the province, the bedded traps have been so much denuded as to expose the underlying formations already described.

The accumulative thickness of volcanic rock in the Girnár mountain

Thickness.

cannot be less than 3,500 feet, but one-half that amount will suffice for the thickness of the bedded traps throughout the greater part of the field.

The trap rocks of Káthiáwár resemble, in nearly every respect, those of the Deccan and Malwa in Peninsular India. Basalts and dolerites mostly prevail, but felstones, trachytes, diorites, and obsidian also occur, and beds of scoriacious breccia are occasionally met with. The several

Varied character.

flows vary considerably in character; those nethermost are often decomposed, and in places agglc

meratic, while the later outbursts are more trachytic, felsitic, and dioritic, occasionally with lenticular masses and thin bands of uncrystallized rock, resembling obsidian, or pitchstone.[1] Some of the trap-flows are thoroughly crystalline, often showing a porphyritic appearance on the weathered surface; others are more homogeneous, compact, and aphanitic; while others again are more or less decomposed, many of these are highly amygdaloidal. In the western part of the field, especially north of Rájkot, zeolites are abundant in the decomposed traps, occurring often in large crystalline masses; and geodes of agate and chalcedony, lined with quartz crystals, are also numerous.

Zeolites abundant.

The traps are, as a rule, thinly bedded: in a scarp of 320 feet, nine miles south of Chotila, one may count, from a distance of many miles, at least eight superimposed flows, thus giving an average of 40 feet for each; but several of them are not half this thickness, and probably there are many more flows than can be superficially discerned. It may be mentioned that the great dyke passing Mewása has cut through all the beds in the scarp just referred to.

The nature of the floor, wherever the traps rest on Umia sandstones, is often irregular and uneven, showing distinct unconformity. The annexed sketch section, showing such an unconformity, was taken in a quarry at the sandstone inlier between 6 and 7 miles west-south-west of Chotila.

Varied floor.

I have already stated that the basal part of the trappean series is frequently very miscellaneous; but this is not always the case; notably in the hilly country west and northwest of Chotila, where a homogeneous trap-flow is seen resting, with apparent conformity of bedding, upon Umia sandstone,

Sketch Section.
α. Trap. β. Sandstone.

[1] It is nearer obsidian than pitchstone; its hardness is from 6 to 7; it is slightly decomposed by acid. Before the blow-pipe, however, a splinter fuses to a frothy light-grey glass.

without any intervention of mingled miscellaneous deposits. The sandstone is here indurated by infiltration of silica.

Volcanic ash in Chotila hill.

In the lower part of the Chotila Hill, there is a thick bed of volcanic ash, made up of fragments, from the size of gravel, or grit, to occasional large lumps of a dense trap: the layers of this accumulation slope at angles of 30 to 35 degrees. The matrix is mostly decomposed, and the rock disintegrating. The upper part of the hill is of fine-grained compact basalt. To the south of the hill the base of the trap is seen to be a very heterogeneous accumulation resting on sandstone.

The trap rocks attain their greatest development in the southern division of the province, where there are several groups of hills of considerable height. Many of these are mainly composed of various kinds of felsite and diorite, with some trachyte and occasionally pitchstone. These rocks appear to be among the later eruptions of the trappean period.

The Gírnár, or Junágarh, group is the most important and interesting, from its singular and imposing form and proportions.[1] The topographical features of this group have often been described,—the great central mass called the Gírnár, over 3,500 feet in height; and the outer annular ridges, steeply scarped on the inner side, but sloping away at varying inclinations outwardly.

The Gírnár a focus of eruption.

The Gírnár mountain is a majestic pile of diorite rock, with terrific scarps and precipices, propped by diverging buttresses, which, inosculating with the surrounding ridges, give rise to four distinct areas of drainage, each discharging through one of the four gorges in the outer ranges. This central pile, which is far loftier than the surrounding ridges (save that to the south, whose highest point nearly rivals it), assumes somewhat the form of a huge cupola, laterally compressed, and is crowned by several sharply defined peaks of an extremely precipitous and picturesque character;[2] the loftiest attains a height of 3,666 feet above sea-level.[3]

[1] See frontispiece.

[2] The crest of the mountain and some of the peaks are adorned with many Buddhistic and Jain temples of richly carved stone.

[3] This paragraph is mainly derived from Mr. Theobald's MS. description, written in 1858.

The Gírnár appears to have been produced by a volcanic eruption of considerable magnitude towards the close of the Deccan-trap period; and the mountain, in its entirety, must have attained vast proportions in comparison with its present denuded appearance. The great central mass now represents so much of the core, or plug, of the vent, the outer portion having been more readily removed by denudation, owing to the decomposition of the component minerals.

Diorite of central peak.

The diorite of this central peak has not been found in any other place in Káthiáwár; nor, as far as I am aware, in any part of Peninsular India. Its normal form is a black and white crystalline-granular rock of hornblende and felspar; it has much the appearance of syenite, but the felspar is almost entirely plagioclastic. This rock passes into micadiorite where it contains black uni-axial mica more or less abundantly, not unfrequently in tabular segregations, enclosing felspar. Some portions of this rock are richer in felspar, with chatoiyant blue lustre, and more coarsely crystalline. Microscopic sections of the rock display magnetic iron, apatite, and garnets occasionally. Other portions are minutely crystalline, or even aphanitic.

Diorite of two kinds.

In the basal and outer portion of the central pile two marked varieties of the diorite are prevalent. The most conspicuous is a light grey semi-aphanitic diorite, with porphyritic crystals of felspar, and some bi-axial mica sparingly; in this variety hornblende is extremely deficient. The other variety is of a dark grey or black colour, from its richness in hornblende, and is often seen intermingled and banded with the paler rock, with which it affords a very striking contrast.

"From the strongly marked line of demarcation which often separates these two varieties in the same rock, it might be presumed that one was of later date than the other, and had penetrated it subsequently to its consolidation; especially as many of what appear like included fragments of the older, have a very angular and irregular outline. But this appearance is in reality deceptive, the pale variety being found enclosing lumps, sheets, and strings of the dark kind, and *vice versâ*, thereby con-

clusively proving the appearance in question to be merely the result of the peculiar arrangements of the component minerals."[1]

Decomposed quartz-diorite in the valley.

The rock occupying the hollow, or valley, between the central peak of Gírnár and the surrounding ranges, is a third variety of the diorite, consisting of a granular mixture of felspar and hornblende, the latter in fair proportion; with free quartz and a sparing addition of rusty black mica. This variety is remarkably prone to decomposition, and at first sight much resembles decomposed gneiss; it is only in the small lenticular masses, which have escaped decomposition, that the true nature of the rock can be detected, its usual condition being that of a friable mass, which crumbles on handling.

Greenstones of the outer ranges.

The surrounding, or outward annular, ranges are composed mostly of various greenstones, to which it is not easy (without a close study with microscopic sections) to assign specific names. Some are felsitic, very tough and compact; others are basaltic, with much olivine: free quartz is not uncommon in a few. These rocks seldom present either the bedded structure, or the terraced appearance, of ordinary trap-flows, so commonly seen in other parts of the district. Yet some of the greenstones appear to slope almost as steeply as the hill-side; while a general outward, or quâquâversal, inclination is perceptible throughout the annular ranges.

Quartz-felsite along the axis.

The axis of the western range, which is very steep, and crested with a precipitous jagged ridge, consists of an extremely tough and durable quartz-felsite, containing plagioclase, quartz, and magnetite in a micro-crystalline base.[2] It has the form of a huge dyke, or vertical intrusion. On the west flank of this western range is a bluff of rock, which assumes the aspect of gneiss, especially in its mode of weathering; but a microscopic examination of a thin section shows it to be a finely-granular quartz-felsite.

[1] Mr. Theobald's manuscript written in 1858.

[2] The "Asoka stone," as it is called, on the polished surface of which is engraved the celebrated edict of Asoka (B.C. 250), is a rounded boulder-like mass of this rock.

Mr. Theobald mentions in his manuscript report[1] the occurrence, on one of the spurs of the hills south-east of Junágarh, of a "small patch (whose exact extent I have not yet traced) "of metamorphosed rock—a coarse quartzite, with bands of conglomerate irregularly disposed through it, containing numerous rolled quartz pebbles." I myself picked up in the plain beyond the western range, a specimen answering this description, an altered conglomeratic quartz grit; but the rock was not found *in situ*, and I take it to be an indurated portion of some pre-trappean bed floated up with the lavas of the period under consideration.

Osham hill.

The hill of Osham, which rises abruptly out of the plain 14 miles west-north-west of Junágarh, is an isolated block, mainly composed of homogeneous trachytic felsite, boldly scarped and presenting in many places beetling cliffs of 200 feet and upwards in height. The eastern base of the hill consists of a soft, decaying amygdaloid, with kernels of a yellow soapy mineral, and quartz geodes. The thickness of this bed is not seen. Above it, but generally concealed by a talus of fallen rock, occurs a bed of pitchstone a few feet in thickness, thinly laminated, but granular and friable in part. These two rocks constitute barely one-fourth of the hill-side, the summit being composed of a thick mass of the trachy-felsite, the fallen blocks from whose steeply-scarped sides conceal to a great extent the softer beds on which it rests. This trachy-felsite is also much laminated, and presents the appearance of woody fibre, which results from the curvature and involution of the planes of lamination, which themselves seem to arise from the movement of the mass when in a viscous, or pasty state; so that the laminæ are often seen horizontal and then bent down, and rolled over, as from the gradual progression of the mass. The surface of the laminæ is either smooth or rumpled.[2]

Pitchstone and trachy-felsite.

The beds in this part of the hill have a slight slope westwards, but in

[1] Season 1857-58.
[2] Mr. Theobald (*loc. cit.*)

the western scarp no succession can be traced. The greater part of this side of the hill consists of a vitreous, aphanitic compact trap; it is banded and contorted, and parts vary from trachy-felsite to obsidian, the latter occurring in alternating layers a few inches in thickness, and following the sharp contortions of the rock mass. Parts of this rock are agglomeratic, with rounded lumps and irregular masses of obsidian, and of a green trap, whose crust, or outer part, passes into the rock mass. Slikensides was observed on a few of the enclosed lumps, the composition of which is often identical with the enclosing matrix.

Barda hills.

The Barda hills consist of rocks very similar to those in the western ridge of the Junágarh mass. A porphyritic quartz-bearing felsite prevails in the northern part of the Barda group; the rock has the appearance of having undergone change, or partial decomposition; it contains free quartz in abundance, some at least of which is a secondary product. It is very similar to the gneissic-looking rock on the west flank of the western ridge of the Junágarh hills. A closely allied rock forms the hills in the southernmost part of the Bardas; but, besides the contained crystals of quartz, there is another vitreous constituent, amber-coloured, and below quartz in hardness. A third variety, associated with the latter, is a pale-grey trachytic ash, which contains a decomposed wax-green soapy mineral. These rocks weather into huge spheroidal, or boulder-like masses, piled one above another. In the neighbourhood of Morpur, and of the deserted place called Gúmli,[1] a very tough granular quartz-felsite prevails; this rock much resembles that forming the axial portion of the western range in the Junágarh hills. The outlying ridge of hill at Dhebar on the north side of the Bardas, consists of a dull fawn-coloured crypto-crystalline, or minutely granular felsite.

Quartz-felsite and trachytic ash.

Hills near Dhánk.

The group of hills north and north-west of Dhánk consists of various kinds of felsites, that would require a closer study than I have been able to give them, to define their

[1] At Gúmli or 'Ghúmli,' a former capital of the Jáitwas (or 'Jethwás'), there are extensive ruins, including some exquisitely carved stone temples.

specific varieties; some are very compact, tough, and silicious; others are trachytic.

Compact earthy felsitic rocks are also met with in several other parts of the trappean area. In the eastern division of the province a laminated, or striped, felsite prevails, as, for example, in the hills at Sihor, 12 miles west of Bhávnagar, and again at Rájula, near Jáferábád. It is often porphyritic and in part agglomeratic. At the former locality the rock is extensively quarried for building purposes, while at the latter place it is worked for querns, or hand-mills.

The Sihor, or Sonpuri, range.

The hills west of Bhávnagar, called the Sihor range, though broken and irregular in outline, have a general bearing east and west. The trap beds, of which these hills are composed, are tilted slightly, showing a tolerably uniform easy slope towards the south, while their northern outcrops form a long scarp running east and west. At the foot of this scarp commences an extensive alluvial plain, which stretches away northward, beyond the limit of the province.

Obsidian and pitchstone.

In the broken hilly ground opposite the town of Sihor, a band of obsidian was observed among contorted and irregular trappean rocks. Mr. Theobald observed a bed of 'pitchstone' in the hills near Rájula. He writes (*loc. cit.*): "At the base occurs a bed of very amygdaloidal trap having much the aspect of some of the Deccan amygdaloids. Above this rests a thick bed of pitchstone not less than 20 feet in thickness, very compact in parts, and these breaking with a highly conchoidal fracture. This bed can be traced for 15 miles to the eastward (E.N.E.), in which direction it gradually dips, eventually disappearing beneath the surface." A bed of pitchstone is also exposed in the Bhádar stream bank at Nágnesh below Ránpur: it is here very impure, enclosing fragments and lapilli of volcanic products; above it is a bed of sphæroidal felsite, whose nodules have a nucleus of chalcedony. Below the bed of pitchstone, which becomes trachytic in the lower part, is a compact felsite of a dull red colour; this latter rock has been used in the wall round the town of Nágnesh.

Chamárdi and Chogát hills.

A group of seven or eight small isolated rocky hills, about 16 miles west-north-west of Bhávnagar, rises abruptly from the alluvium, presenting the appearance of mountain tops that have escaped submergence. The largest and highest of the group is nearly a mile long and reaches an elevation of 340 feet above the plain, which is scarcely 20 feet above sea-level. These hills, which may be called the 'Chamárdi group,' are composed mainly of similar rock to that found in the Bardas and in a part of the Gírnár; and they would seem to indicate another centre of eruption. Those nearest the village of Chamárdi consist of quartz-felsite rich in felspar, and approaching syenite. Though a solid-looking rock in a hand specimen, it weathers unevenly, and is not valued as a building stone. That in the hill south of the Chamárdi stream is a greenish grey and dark crystalline diorite; a similar rock, but more distinctly crystalline, giving a black and white appearance, forms the larger of the Chogát hills, while the smaller consists of a compact and very hard felsite.

Inter-trappean beds.—Sedimentary deposits interstratified with the trap flows are seldom met with in Káthiáwár, and the few places where they have been observed are situated at no great distance within the northern margin of the trap area; and, as usual in other parts of India, the inter-trappean horizon is not far from the base of the formation.

Porcellaneous shale west of Chotila.

A cherty porcellaneous shale crops out from the sides of the hills near the road, two or three miles west from Chotila, and is seen again to the south, in the broken ground round about the villages of Kherdi and Kálásar. The bed is more conspicuous near Bámanbor and Nawágám, about ten miles from Chotila, on the road to Rájkot. At this latter locality some organic remains, mostly imperfect skeletons of very small fish, were detected, but they are not abundant. The shale here displays evidence of severe lateral compression, the laminæ being crumpled into small folds that give the appearance of ripple mark to the surface of each stratum.

Limestone at Ninámá, &c.

The fort hill of Ninámá, twelve miles south-east of Chotila, is capped with a bed of inter-trappean limestone. The same bed is seen cropping out near the top of an adjacent hill; and it was again observed capping the ridge scarp between Lákháwand and Shekdod. The bed is there sloping, at a low angle, southwards, in which direction it becomes covered up by later flows of trap. The maximum thickness is about ten feet, and the rock consists of argillaceous limestone, very tough, close, and in part cherty. At Ninámá it is somewhat flaggy, or roughly banded, and has been largely used in building the walls of the fort.

The Sardhár dyke.

Trap dykes.—In certain parts of the province,—more especially in the central and south-eastern portion of the trappean area, and in the jurassic field beyond the present boundary of the traps,—dykes are very numerous and large, often forming prominent features in the landscape. Many of the dykes are traceable for long distances; the large Sardhár dyke extends for about 45 miles from end to end, and in some parts has the appearance of a great rampart in ruins. At Sardhár, it is nearly 100 feet across. The general bearing is east and west, this being the prevalent direction of the dykes in that part of the country; though they may be irregular for some portion of their course, and even interrupted or not visibly persistent throughout; or they may bifurcate. Several cross-dykes bear north and south, or north-by-west and south-by-east, and are generally of a later date than the east and west set. Indeed, the dykes are so prevalent and strongly displayed, that they can hardly be regarded otherwise than as indications of the fissured and crevassed state of the stratified crust of the earth during the period of the trappean eruptions.

Sources of discharge.

Surprise has often been expressed at the absence of volcanic vents within the trappean area, but the fact, that the Deccan trap period was a period of fissure eruption, is not sufficiently borne in mind. When we contemplate the

enormous volume of discharge that these numerous and extensive fissures afforded, there is no need to look for volcanic vents, or *foci,* although, in the Gírnár mountain and a few other hills, there is some evidence of the latter kind of discharge at the close of the trappean outflow.

Nature of dyke-trap.

The character of the dyke-trap generally differs from that of the adjacent flows, or beds; this may probably arise from the difference of condition under which the matter solidified. The rock, in very many of the dykes, has a prismatic, or columnar structure, transverse to the direction of the dyke. In very few instances was the dyke-trap observed to be amygdaloidal, or vesicular; and where such is the case, it may be presumed to occur near the surface, or overflow: at this latter point a dyke would naturally become ill-defined and blended with the lateral flow. This, indeed, appears to be the case in the dyke at Harmaria, north of Mewása, where the dyke-rock, in places, is indistinguishable from the adjoining bed, or flow, and is only traceable as a dyke here and there by irregular lines of contact.

Variety in aspect.

The long dyke west of Charkhari (north of Mewása) displays a different structure at different levels within its walls; where seen in the bed of a *nala* it has a fissile splintery structure, is very close-grained, or micro-crystalline; while, at a higher level of the same dyke in the hill ridge above, the rock has lost the characters just described, and has assumed a spheroidal, or boulder-like, structure on the weathered surface, and internally is more distinctly crystalline.

The Khokhri dyke (south of Gondal) is 120 feet wide east of the town, and may be as much as 200 feet in some parts, but its decomposed sides and walls are not clearly defined.

The great dyke running eastward from Karmál Kotra, and twice crossed by the Bhádar river, east of Gondal, is more like an irregular intrusion than a fissure dyke. It is very irregular without definite walls, and in one place it has a bedded appearance.

Among the dykes north of Wasáwad, those in one direction are of one kind of trap, while those crossing are of a different kind. The north-east, and east-north-east, set have a crystalline texture, with grey felspar and black hornblende; the rock is massive, or transversely columnar: while the north-west and south-east dykes have a much finer texture, are micro or crypto-crystalline, and the rock—which is dark grey internally, but weathers to a pale olive green on the surface—is fissured into angular shingle, or gravel, along the surface of the dyke. This latter set, it would appear, is the older; for, in several instances, the dykes of this series were cut through by those of the other. It was also observed that the dykes with the splintered fine-grained trap with olive green surface (*i.e.*, the older dykes) are more regular, on the whole, than the others: they are long and straight in their course, or nearly so, and uniform in thickness throughout: they seldom make much show above the surface of the country, at most forming low knolls, or elongated mounds, hardly perceptible from a distance; whereas the more crystalline lumpy boulder-like trap-dykes are most irregular in their bearing, vary much in thickness, and often die out rapidly, or terminate abruptly, starting again, perhaps, a little out of the normal bearing. They almost invariably form ridges that may be traced by the eye across country for many miles. Some of these ridges attain a height of 150 feet above the level of the surrounding country; as, for example, the one north-east of Kotra Pita that passes the deserted village called Bhabhisana. These ridges are buttressed, or fringed, on either side by remnants of bedded traps removed elsewhere by denudation.

Differently bearing dykes have different kinds of trap.

There are exceptions to the rule given above, that dykes trending in one direction bear the same kind of trap; for instance, of the eight dykes more or less parallel, north of Dárwa, and all within two miles of the village of Umrála, five are of the fine-grained trap that weathers on the surface into angular gravel, while three are of a coarser variety of trap weathering into large boulder-like masses.

Exceptions.

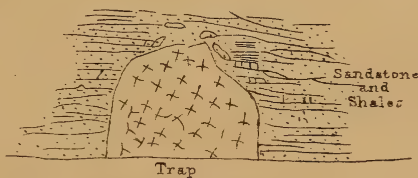
Many of the larger dykes are strongly magnetic, owing to the amount of magnetic iron entering into the composition of the rock.

Dykes in Umia sandstones.

The ground, in the south-western part of the jurassic field, to the north of the present limit of the trappean area, is closely intersected by trap dykes, more especially in the neighbourhood of Thán, where they form quite a tangled network on the surface of the country.

Some of these filled-in rents are traceable for a distance of 30 miles; others may be equally extensive, though not continuously exposed, their several parts not being visibly connected.

While certain of the dykes may be traced to within the trappean area, where they have penetrated vertically through 300 or 400 feet of bedded basalts, others do not persistently reach the surface even of the sandstones. The annexed sketch of a section in the bank of the stream between Sarsána and Morthala, north-west of Thán, will illustrate the latter instance. The dyke here shown was traceable in the bed of the stream, and again further on, after being lost on the surface for a short distance.



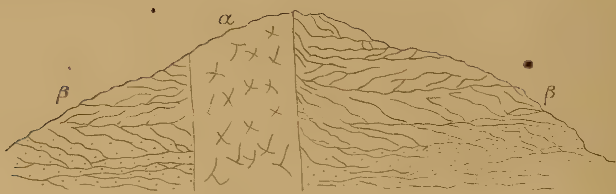
Sketch Section.

The dykes in this neighbourhood are mostly of large size, few being under 8 feet in width; one north of Thán measured 32 feet, but there are others still broader. Occasionally a partition occurs along the middle of the course, formed by a mass of sandstone detached from the walls. The walls, as a rule, are vertical, or very nearly so, with clean well-marked faces, and often coated with silicious slickensides, as are also the sides of the enclosed masses.[1]

Slickensides on the sandstone walls.

[1] Some excellent examples were obtained of enclosed pieces of sandstone with slickensides on either side, and so intensely indurated as to resemble gneiss. They are now exhibited among the physical specimens of the Survey Museum.

Other evidences of great compression, and vertical motion, are displayed in the up-turned edges of the adjacent beds, not unfrequently seen on one or other side of the dyke, as shown in the accompanying sketch section.



Sketch Section
α. Dyke. β. Sandstone.

The effect of a dyke, on the sedimentary beds traversed, is generally to indurate, and at times to blacken or to bleach the rock for a short way on either side: and the hardened portion, being the better able to resist denudation, often remains as a narrow craggy ridge along the course of the dyke. This feature, together with that of the upturned edge of the wall-rock, enables one to trace the course of a dyke, even when no trap is visible on the surface.

The dyke-trap in this part of the field is almost invariably either a fine-grained compact blue-black basalt, or otherwise is in the decomposed state of '*wacke*'; it is never largely crystalline nor porphyritic, as many of the bedded flows are. The basalt of the dykes, as previously stated, is usually columnar, the prisms lying horizontally, and transverse to the direction of the course, *i.e.*, at right angles to the walls, and in the line of greatest resistance; whereas the prisms of bedded columnar trap are generally at right angles to the bedding.

Dykes transversely columnar.

In the broader dykes the trap may be columnar on either side, and decomposed in the middle, or *vice versâ*. This transversely columnar structure being peculiar, enables one to detect a dyke and note its direction when there may be no other indications.

Some of these basaltic dykes, having resisted the denuding agencies more effectually than the neighbouring rocks, stand up like the ruins of a great boundary wall across the country: a fine example may be seen just within the hilly ground 4½ miles south-west of Chotila.

No system as to the bearing of the dykes in the jurassic area could be traced, for they trend in all directions.[1]

Intrusions north of Chotila.

There is, about a mile and a half north of Chotila, a small group of irregular intrusions of fine-grained compact blue-black basalt. That these are actually intrusions, and not remnants of a trap flow, is shown by the altered indurated state of the adjoining sandstone; and further evidence is afforded in the frequent occurrence of slickensides here, caused by the pressure of the out-flow.

Dykes numerous in south-eastern area.

Numerous large dykes are shown on the map in the south-eastern part of the trap area, in the vicinity of Dedán, and thence north-eastward as far as Talájá. The hill ridges, formed by these dykes, have been so clearly delineated by the Topographical Survey, on their large-scale map, that I have not hesitated to colour the dykes on them, as time could not be spared to traverse the whole area. It will be seen that the general bearing of the dykes in this part of the field is west-40°-south to south-west. A few cross nearly at right angles. In the north-eastern part the bearings are less regular.[2]

Distribution.

Lateritic rocks.—This group, in the southern and south-eastern divisions of the province, is only exposed in a few places along the margin of the trap area; notably,

[1] It was observed that the agriculturists persistently sink their irrigation wells along the dykes, tracing out their course with great assiduity; they are almost invariably rewarded by the wells yielding water at a depth within 15 to 20 feet of the surface. In some instances it would appear that the joints and cracks in the dyke-rock communicate with some deep-seated water-bed; in other cases the dykes seem to wall up, and keep in on one side, the water of the adjoining strata.

[2] The map published with this memoir is on so small a scale, that only a limited number of the dykes can be shown; very many more have been recorded on the large field-map in the Geological Survey Office.

to the south of Bhávnagar, where it occupies a continuous though narrow belt, about 20 miles in extent. It is for the most part overlapped by tertiary and alluvial deposits. In the western division of the province, however, where the trappean floor is nearly horizontal, some large spreads of the lateritic rocks occur along the border between the traps and tertiaries; also as outlying patches resting on the former, and as inliers well within the area of the latter formation. These inliers are in the form of hillocks, crags, and bluffs rising over the plain, having resisted the denudation prior to the deposition of the tertiary beds that surround them.

The lateritic rocks in Káthiáwár closely resemble in many respects those in the neighbouring provinces of Cutch and Guzerat; and are to all appearances identical with the 'high-level laterite' and its associates of Peninsular India. They are generally unstratified, richly coloured, mottled, or white; the more lateritic bands are frequently strongly ferruginous, developing into red hæmatite.[1]

Varieties of the rock.

Among the laterites may be noted a softish earthy rock of lavender-grey colour, blotched with a white decomposed mineral; another variety is a concretionary and partly conglomeratic grit, of argillaceous pellets and nodules in a dark ferruginous matrix: a third is a decomposed brecciated ash, or tuff, consisting of white and faintly mottled soft soapy clay (in places indurated and deeper in colour), enclosing lumps and lapilli of similar rock, but more richly coloured and more earthy than steatitic; these enclosures sometimes form the bulk of the mass. This last variety was observed in a large excavation for a well at the village of Bakharla, north-north-east of Porbandar, and at other places in that neighbourhood. Its position is below the strongly ferruginous and lateritic beds of the rising ground to the west of the village. The same kind of rock was also seen near the base of the lateritic section west of Habardi, south of Asota, near the Gulf of Cutch. The

[1] This ore was largely worked and smelted in former days, but the industry was given up about forty years since owing, in great measure, to thec heapness of the imported metal.

indurated ash occurs in the lateritic area about three miles south-west of Asota. The second variety mentioned above may be seen to the east of Visawara above Porbandar.

Much of the ferruginous red or mottled earthy rock has the appearance of decomposed and lateritized volcanic ash; that at Tukra near Miáni,—in the form of craggy hillocks, or rising ground, sometimes supporting a remnant or thin capping of tertiary beds,—contains semi-crystalline lumps of a white partially decomposed mineral, which is probably of secondary origin; it is too much altered for recognition. The same, or very similar, rock appears about the middle of the lateritic section in the hills on the west of Asota. About a mile north-by-west of Bhátia, the dark-red ferruginous rock presents the appearance of a porphyry, as it contains a white steatitic, or kaolinic mineral, in the form of decomposed crystals, scattered through the mass.

Thickness.

It is evident that the lateritic formation must have been subjected to a considerable amount of denudation, prior to the deposition of the sedimentary tertiary beds in Káthiáwár; for its average thickness does not probably exceed 50 feet, while there are places where such extremes as 200—250 feet are reached.

Volcanic origin.

The material of the rocks of this formation has undergone so much change, by decomposition and 'lateritization' (if I may be allowed the term), that its original aspect, or primary condition, has ever been a subject of conjecture and speculation; but there appears good evidence, in the character of some of the Káthiáwár rock, that the original material was mostly volcanic ejectamenta, and that the group represents an eruption subsequent to, and differing in many respects from, the trap out-flows.

Gáj beds.—The post-trappean formations occupy the margin, or border land, of the trappean area in the southern half of the province, having the coast line for its outer boundary. This belt of country averages about seven miles in breadth. No Gáj, or other tertiary, beds occur along

the southern shore of the Gulf of Cutch east of the lateritic rocks in the vicinity of Asota.

Position.

The rocks of the present group are, however, only found in portions of the marginal belt, being exposed at intervals in the south-eastern part of the field, while the largest spread of Gáj rocks occupies the boundary country between Hálár and Oká-Mandal. Within this latter area the beds are readily recognised by their fossils, which in places are very numerous.

Thickness.

The beds everywhere are so nearly horizontal, that any continuous vertical succession cannot be expected in so flat a country: scarcely any individual section can show more than 40 or 50 feet of strata, while the aggregate thickness of the Gáj beds alone must amount to several hundred feet.

South-eastern area.

In the south-eastern part of the field, rocks of tertiary age are only met with very sparingly. There are a few isolated outcrops along the margin of the traps and laterites, and some inliers in the alluvium, mostly too small to be marked on the map accompanying this paper; besides a rather large spread in the Gogha district, which includes the little island of Piram (Perim)—long renowned for its abundance of fossil bones and fossil wood. I have included all tertiary beds of this south-eastern area in the present (Gáj) group. They are quite unconformable to the lateritic rocks on which they rest in the northern part; while in the south, the latter are absent, and the tertiary beds are seen in places to rest directly upon the traps. The fossiliferous beds of western Káthiáwár have no place in the present area; it would appear that they are here deeply overlapped by other beds which I am disposed to regard as representing the uppermost portion of the Gáj group. Indeed, some of these beds closely resemble certain members of the Manchhar group in Sind, where, though almost entirely of fluviatile origin, it contains in a few places bands with Gâj fossils, intercalated above the base of the group. There are also other indications that there was no break in time between the two groups.[1]

[1] See Manual, Geol. Ind., pp. 342, 468, 469; and Memoirs, Vol. VII, p. 188.

In this south-eastern area there is no good section exposed anywhere, and the country, having a fairly rich soil, is mostly under cultivation. The streams are all shallow, with only short and well-separated outcrops of nearly horizontal marls, shales (some of which are gypsiferous), clays, and a few ferruginous conglomeratic deposits, some of which may indeed be only superficial and of more recent age. This is more particularly the case in the northern part of the area towards Bhávnagar.

No good sections.

About a mile from Akwára on the road to Bhávnagar, in a small stream-course, a rusty conglomerate of clay pellets or galls and agates, passes down into a soft marly rock, bearing crystals of gypsum. Marine fossils are rather abundant in these beds; a number of spines of *Echinus* were collected from the weathered surface, together with fragments of *Pecten*, *Ostrea*, and a buccinoid shell resembling *Voluta jugora*, but too poorly preserved to be identified; also, a reptilian tooth, a fragment of a molar of *Mastodon*, a small encrusting coral, and bryozoa. Bored clay pebbles also occur in the conglomerate.

Fossiliferous conglomerate near Akwára.

Similar marine fossils were also found near the village of Bhumbhli (3 miles from Gogha), at the tank to the south of the village, in cross-bedded coarse sandy, and hard calcareous grit; this rock also encloses small agates derived from the traps. The fossils include *Pecten*, *Ostrea*, spines of *Echinus*, and a shark's tooth, besides others not determined. This grit rests, with slight unconformity, upon clay shale, the base of which is not exposed.

Further to the south, in the stream-course above Rámpur, a strong bed of ferruginous and agatiferous conglomerate, or coarse grit, rests on bluish-grey clay-shale; below which come rusty sandy grits, very similar to that at the Bhumbhli tank. They vary much in texture, even in different parts of the same bed; and contain layers of purple mottled clay.

Agatiferous conglomerate.

At Kharaslia, a village between seven and eight miles to the south of Bhumbhli, the agatiferous conglomerate is seen at the little fall in the

stream on the east of the village. The upper part of the bed is hard, compact, and black in colour; while that below is of a light rusty colour, not so hard and in part a mere gravel; it is unlaminated, and towards the base becomes argillaceous. Above this bed is a compact layer of yellow calcareous sandstone, with raised markings on the surface, like annelid tracks; and in another part a laminated ferruginous sandstone varying in texture, and not persistent. Indeed, the section exhibits much irregularity in the deposition of these rocks, the individual members not being continuous throughout. Some fossil wood occurs sparingly in the agatiferous bed.

In another place farther up the same stream, the following section was observed (descending):—

1.—Dark earthy and coarse soft sandstone.

2.—Agatiferous gravelly conglomerate, with bands and irregular partings of dark ferruginous sandstone.

3.—Light-yellow, and then pale-bluish white clays.

There appears to be a considerable thickness of this clay, but it is not well exposed, being overrun by debris, and displaced by rain and weather. The clay is used by the villagers for washing purposes. No fossils were detected here.

Hill ridge west of Háthab.

The agatiferous bed is most conspicuous and strong on the hill ridge, two miles west of Háthab (six miles south of Gogha). It is here a hard ferruginous, red and yellow, arenaceous conglomerate, enclosing some large pebbles of quartzite and flinty agates. This rock forms the crest of the ridge, and rests upon a thick-bedded mottled yellow clay, which passes down into rusty-brown, coarse, earthy sandstone, with a few runs of agate gravel. It would appear that there is a great overlap here, for the lateritic rocks are seen shortly, in the plain below the west flank of the ridge.

The stream passing Bári, Hoidar, Gundi, and Háthab does not afford any clue to the succession of the beds; though it crosses from the trap area, through the lateritic zone, and traverses the whole breadth of the tertiary area to the coast, and is the largest stream in this part of the field.

Some Gáj beds are exposed in the steeply scarped coast line, about a mile and a half below the mouth of the stream just mentioned. A yellow and marly 'rag' bed is the most conspicuous; from it an inferior building stone has been extracted for the Thákor's summer-house, lately built on the high ground above the scarp. The rock is for the most part saline, and weathers rapidly on the surface into a fine powder. From this rock the following fossils were obtained :—

PELECYPODA.

Venus, sp.? (cast).
Pecten, comp. *corneus*, Sow.
P. sp.?
Ostrea, sp.? (very small).

BRYOZOA.

Lunulites, sp.? (abundant).

ECHINODERMATA.

Cidaris, spines.

In one place a close clay-shale, pale greenish in colour, is seen resting upon the marly limestone; no fossils were detected in the shale.

Coast flags at Gogha.

In the tide way along the coast at Gogha, and for some distance towards Kura, there are very fine soft silty flags and sandstones, that harden considerably on exposure to the air, when they form a fair paving, or flooring stone, and are largely used for that purpose in Bhávnagar. At Gogha itself, the sandstones are coarser and rusty brown in colour; with conglomeratic bands and layers among them, enclosing clay pebbles and ferruginous galls. These rocks have all the appearance of identity with the beds of Piram.

Piram Island.

This little island, which "is simply a reef of rock covered in part by blown sand,"[1] is situated about four miles off the coast opposite Háthab, six miles to the south of Gogha. Captain R. E. Ethersey, I.N., in a paper read before the Bombay Geographical Society in 1838, mentions that it is 1,800 yards long, and 300 to 500 yards wide, lying north-north-west and south-south-east; and

[1] Blanford: Memoirs, Geological Survey, India, Vol. VI, Part 1, p. 212.

is surrounded by an extensive rocky reef. At low-water spring tides, the channel between the Piram reef and a rocky reef towards the mainland is only 1,200 yards wide, and has the extraordinary depth of 360 feet, with a bottom of yellow clay. Sandhills line the west side, and both ends of the island: their general height is from 20 to 40 feet. The south-east side is low and sloping towards the Gulf of Cambay.

Discovery of fossils in 1836.

Dr. Falconer, in his paper in the Quarterly Journal of the Geological Society of London (Vol. I, 1845), states that the first announcement of the Piram fossils was given in a communication (to the Secretary of the Asiatic Society of Bengal), dated April 1836, and published in the May number of the Journal for that year, by Baron Carl von Hügel, in which he mentions their having been discovered by Dr. Lush.

Piram island is also mentioned by Dr. George Buist (March 1855), in the Transactions of the Bombay Geographical Society (Vol. XIII). He observes that the island, at low water, exhibits twenty times the area it presents at high water—being in the former case nine miles in length and three miles across;—and that "the bones and other petrifactions, found in such profusion thirty years before, when the place first became known to geologists, have been so largely drawn upon by travellers, that they are now (1855) very rarely to be met with *in situ*, though some baskets-full are always brought by the fishermen for sale to the travellers"; "and it is singular (he remarks) how correctly they are generally named by these simple people, who, it is to be presumed, are in this only repeating what they have been told."

If the fossils were becoming scarce in 1855, it is no wonder that goo specimens are now, 1883, rarely to be obtained.

In Captain Ethersey's paper, above cited, is given a carefully measured section of the bluff at the southern end of the island; it is as follows:—

SECTION, DESCENDING.

(*Beds horizontal.*)

	Feet.	Inches.
Reddish mould mixed with stony rubbish	3	0
1. Yellow puddingstone	1	6
2 Sandy clay	1	0
3. Dark coloured puddingstone	0	6

	Feet.	Inches.
4. Sandy clay	4	0
5. Yellow puddingstone	1	0
6. Sandy clay	0	6
7. Recent sandstone	0	6
8. Sandy clay	8	0
9. Yellow puddingstone	1	2

The beds are roughly horizontal, and he truly observes, "None preserve an uniform thickness throughout the cliff." Number 7 of Ethersey's section is evidently a very soft recent-looking sandstone. Numbers 1, 3, 5, and 9 are sandy conglomerates, rather than 'puddingstones.'

Captain Fulljames describes[1] the order of succession, commencing from the surface, as thus :—

1. Loose sand and gravel.
2. Conglomerate, composed of sandstone, clay, and flints.
3. Yellow and whitish clay, with nodules of sandstones.
4. Conglomerate, as No. 2.
5. Calcareo-silicious sandstone, with a few fossils.
6. Conglomerate.
7. Indurated clay, more or less compact.
8. Conglomerate, being the principal ossiferous bed.

No precise measurement is given of these beds, but the thickest conglomerate is described to be about 3 feet, although, in general, they do not run more than 18 inches to 2 feet.

These sections are really of no value as indicating any regular succession of strata; the little island consisting merely of a number of conglomeratic beds, alternating with soft sandy silts and silty shales. Some of the conglomerates are very coarse, with large imbedded lumps of a yellowish, or greyish-brown sandstone; others are composed mostly of concretionary sandy nodules, often black in colour, some of them very large and assuming queer fantastic shapes.[2]

[1] Journal, Asiatic Society, Bengal, Vol V, p. 289.

[2] Mr. Blanford observes (Mem. Geol. Sur. Ind., Vol. VI, p. 374), "The conglomerates belong to two forms, very distinct in appearance, but both containing bones. The most prevalent is an extremely coarse rock, made up of rounded blocks of sandstone, varying from 3 feet in diameter downwards, but mostly not exceeding a foot, and very irregularly shaped. The sandstone is generally of fine texture, and grey or light brown in colour. This conglomerate is usually more or less nodular, and occasionally the bed appears chiefly made up of nodular concretionary pebbles, which, when weathered, strongly resemble casts of large univalve shells. The matrix of the pebbles which form the bulk of the rock is a coarse

The deposition of the conglomeratic rock is very irregular, at times presenting a tilted appearance, the effect of false bedding. I may here remark that the observations by several writers, of high dip and disturbance of the Piram beds, are a misinterpretation of the oblique and irregular nature of their deposition. As already stated, the strata are, on the whole, about horizontal. The beds vary in thickness from two feet downwards, and occasionally thin out altogether.

Some of the intermediate, or partition, beds of sandstone are but slightly coherent, being a grey finely micaceous laminated sand (hence Captain Ethersey's term 'recent sandstone'); others are more impure, muddy, and silty,—a sandy mud deposit. A few are shaly.

Position of fossil bed.

Nearly all the conglomeratic beds are, more or less, ossiferous; the higher ones less so: but it is one of the lower, and perhaps rather more ferruginous, beds that has proved so prolific in fossil wood and bones. This bed is situated considerably below the level of high water; and for more than half the year, is obscured by a thick covering of mud. During the months of April, May, and June, the fossil ground, or the south-eastern end of the reef, becomes scoured and free from mud; when the village men search for specimens at low tide, finding them washed up by the surf. The principal fossil bed cannot, therefore, be included in the section of strata quoted from Captain Ethersey's paper; as there he mentions that the lowest bed of it is washed by the high-spring tides. A considerable amount of uncertainty has hitherto existed regarding the proper position of the principal fossil-bearing band, but my observations show that it is as above stated.

The bones I saw *in situ* and otherwise, in my search over the exposed part of the reef, were few and far between; they present all the appearance of having been broken, and much worn, prior to deposition. Large

sandstone, containing small rounded fragments of agate and quartz, rarely exceeding an inch, and generally below ¼ inch in diameter.

"The second principal variety is the same coarse sandstone with agate pebbles, the latter, however, being neither numerous nor conspicuous, without any of the rounded blocks of sandstone."

masses of fossilized drift-wood, many of them bored by *Teredo*, are not at all uncommon in the lower beds.

The following is a list of the fossils that have been found in the island :—

VERTEBRATA.

PROBOSCIDIA.

Mastodon perimensis, Falc. and Caut.
,, *pandionis*, Falc.
,, *latidens*, Clift.
Dinotherium indicum, Falc.

UNGULATA.

Sus hysudricus, Falc. and Caut.
Bramatherium perimense, Falc.
Acerotherium perimense, Falc. and Caut.
Hyotherium, sp.
Hippotherium theobaldi, Lyd.
,, *antilopinum*, Falc. and Caut.
,, ? sp. nov.
Rhinoceros sivalensis, Falc. and Caut.
Camelopardalis sivalensis, Falc. and Caut.
Crpra perimensis, Lyd.

CROCODILIA.

Crocodilus palustris.
Gharialis gangeticus.

CHELONIA.

Colossochelys atlas, Falc. and Caut.
Testudo, sp.
Trionyx, sp.

PISCES.

Vertebra of Shark.

And the *Teredo*-bored wood, which is mostly endogenous.

There can be little doubt that the Piram beds are a marine, or at least estuarine formation (though the terrestrial remains indicate the near existence of land), and that they are one and the same formation as that of the Gogha mainland, in which, however, the ferruginous conglomerates are less conspicuous, and fossil bones very rare.

Coast rocks south of Gogha.

Following down the coast, we find, at Mitiwiri, a rusty brown hard gritty sandstone with vertical annelid tubes, exposed in the *nala*. In the scarp of the hill hard by, are seen about 30 feet of beds of similar rock, having woody-looking markings, with gravelly runs and coarse parts of quartz pellets well polished, and small agates; loose gravel also occurs between the harder beds. This rock probably represents the agate conglomerate mentioned before. No other rock is seen, and sand-drifts and dunes fringe the shore; but below high-water mark there is a very ferruginous raggy gritty sandstone.[1]

In the stream-course at Jhinjhka, near Dongar west of Mhowa, some masses of yellow-buff marly limestone are seen resting on soft argillaceous rock not well exposed. In the limestone an *Ostrea*, some small corals, and other minute marine organisms, were detected; and some detached masses of coral, lying about in the stream course, were evidently derived from the same rock. Among the specimens collected, the coral *Stylocœnia vicaryi*, Haim., has been determined.

Fossil bed north of Jáferábád.

An outcrop of Gáj rock is again seen for some way along the bank of the stream that passes Kágwadar, at the bend, a mile and a quarter south of the village, and about 6 miles north of Jáferábád. It is a yellow marly limestone, with numerous fossils; indeed this locality proved the most productive of any in eastern Káthiáwár.

The following is a list of the fossils so far as I have been able to determine them :—

ZOANTHARIA.

Calamophylia?

[1] A spring of sweet water wells up through several orifices in this rock.

BRYOZOA.

Escharia halaensis.
Discoflustrella vandenheckei.

PELECYPODA.

Venus granosa, C. Sow.
„ sp.
Dosinia pseudo-argus, d'Arch. and Haim.
Pectunculus pecten, C. Sow.
Pecten, sp.
Cardium triforme, C. Sow.
„ sp.
Cardita (indet.)
Arca kurracheensis, d'Arch.
Ostrea, sp. (small).

GASTEROPODA.

Cypræa humerosa, var., C. Sow.
Natica (indet.)
Pyrula ? sp.
Fusus (indet.)

In some shale (very sparingly exposed in the side of a small *nala* between Nátej and Umes, about 4 miles north-east of Uná) I obtained a stunted variety of *Ostrea multicostata*, and the common *Placuna* of the Sind Gáj beds.

The next exposure of Gáj rock is an inlier, 3 or 4 miles in extent, at Wasáwar, 14 miles east of Pátan. Yellow shaly and flaggy limestones prevail, in which *Pecten corneus*, C. Sow., is very conspicuous. This *Pecten* zone was also frequently met with in the western extremity of the peninsula, in the country east of the *ran* that separates Oka Mandal from the mainland.

South-west coast.

Continuing on further round the coast, some 12 miles north-north-west of Verâwal there is a large spread of Gáj rock. It consists mostly of a yellowish close limestone, more or less argillaceous, and composed largely of fragmentary

organisms, among which any distinct or recognisable fossil can seldom be detected. At Khorása, east of Chorwar, the rock is a hard tough marly limestone, buff coloured, with numerous fragmentary fossils of bryozoa, corals, &c. A coral mass of dark close limestone was also observed in this locality.

The Gáj rocks continue, for some distance north-westerly, as an irregular fringe along the margin of the traps, with only a very narrow band of the lateritics intervening. They are broken through at the mouth of the Oját river, where the rocks have undergone much denudation; and the alluvium overlapping them has invaded the trap area for some way up the valley.

The tertiaries are nowhere exposed in the delta of the Bhádar river; nor seen again till the latitude of Porbandar is reached; where a broad spread extends for about 17 miles near the coast, to within a few miles of the Miáni creek.

The boundary lines within this area are complicated, on the one hand, by inliers of lateritic rocks, which protrude as crags and hummocks considerably above the present level of the tertiaries; and, on the other, by invading inlets of alluvium, where denudation has permitted it. Much of the ground north and north-west of Porbandar is sheeted with miliolite and other sub-recent accumulations, which along the seaboard form a succession of beds of solid rock, and it is by no means an easy matter to lay down a boundary line between these and the tertiary beds.

At Bhárwára, nine miles north of Porbandar, a yellow marly limestone contains numerous coral stalks (*Stylophora*), a few single corals, and, more sparingly, the rotund variety of *Venus cancellata;* one specimen of *Turritella vittata* was also obtained.

In the neighbourhood of Visáwár, six miles below Miáni, and at Túkra, two miles nearer Miáni, very rag-like disintegrating Gáj beds yielded the following fossils :—

CEPHALOPODA.

Sepia, sp. (cuttlebone).

GASTEROPODA.

Turritella subfasciata, d'Arch. and Haim.
 ,, *angulata,* C. Sow.
Natica, sp.
Trochus loryi ? d'Arch. and Haim.
 ,, *cumulans ?* Brong.
Cerithium rude, C. Sow.
Cypræa humerosa, C. Sow.
 ,, *nasuta ?* C. Sow.

PELECYPODA.

Cucula trigonalis.
 ,, sp. (comp. *fava* et *striata*).
Dosinia pseudoargus, d'Arch. and Haim.
Astarte hyderabadensis, d'Arch. and Haim.
Venus granosa vel *cancellata,* C. Sow.
 ,, *non-scripta ?* C. Sow.
Cardium triforme, C. Sow.
 ,, *picteti,* var ? d'Arch. and Haim.
 ,, *brongniarti ?* d'Arch.
Pectunculus pecten, C. Sow.
Pecten bouei, var. α, d'Arch.
 ,, *favrei ?* d'Arch.
Placuna, sp.
Ostrea multicostata. Desh. (fragment).

BRYOZOA.

Gen. et sp. indet.

CRUSTACEA.

Chela of Crab.

ECHINODERMATA.

Echizaster, sp.
Cidaris (spines).
Clypeaster ? depressus, C. Sow. (fragment).

POLYPES.

Cladacora ?
Pachyseris murchisoni, J. Haim.
Trochocyathus, sp.
Cyclolites.

Beyond this tract the traps come down to the sea-shore, and extend along the coast for about seven miles above the Miáni creek; thence the trap boundary trends, in a very irregular and tortuous line, northwards to the shore of the Gulf of Cutch. West of this line the whole country, including the Oka Mandal *taluk*, is covered by tertiary and higher rocks. Of these the Gáj beds prevail on the mainland, while an overlying series, possibly of later age than tertiary, occupies the greater part of Oka Mandal. There are, however, some small inliers and outcrops of Gáj rock along the eastern side of the latter area. No appreciable disturbance from the original horizontality of the beds was observed, except to the north of Gurgat and Pindára, where there is a gentle but distinct slope northwards, carrying the beds under the Gulf of Cutch.

From the outcrop in the stream bank at Pindára the following fossils were obtained:—

GASTEROPODA.

Natica, sp.
Cypræa, sp.
Eburna, sp.
Turritella angulata, C. Sow.
Phasianella ? comp. *oweni*, d'A. & H.

PELECYPODA.

Dosinia pseudoargus, d'A. & H.
Astarte hyderabadensis, d'A. & H.
Venus nonscripta, C. Sow.
Cardium triforme, C. Sow.
Pecten bouei, var. α, d'Arch.
„ *favrei*, d'Arch.
Scapula ? indet. (or *Modiola* ?).
Pullastra virgata ? (or *Venus subvirgata ?*).
Placuna, sp.
Ostrea multicostata (small).

ECHINODERMATA.

Schizaster granti, Dun. & Sla.
Cidaris halaensis, d'Arch. & Haim.
Clypeaster, sp. indet.
Temnechinus, sp.

Another, and more prolific fossil locality, is at an excavation for a small tank three miles east-by-north of Gága, and 4½ miles south-east of Gurgat. The following fossils were collected at this place :—

CEPHALOPODA.

Nautilus, sp.

GASTEROPODA.

Natica callosa, C. Sow.
„ sp.
Voluta edwardsi, var. *α*, d'Arch.
Cassis, sp.
Strombus fortisi (*?*), Brong.
Buccinum fittoni, d'Arch. & Haim.
Phasianella oweni (*?*), d'Arch. & Haim.
Trochus cognatus, C. Sow.
„ *cumulans*, Brong. (? young).

PELECYPODA.

Venus non-scripta, C. Sow.
„ *cancellata*, C. Sow.
Cyprina transversa (*?*), d'Arch. & Haim.
Tellina sub-donacialis, d'Arch. & Haim.
Arca hybrida, C. Sow.
„ *toruosa*, vel. *kurracheensis*.
„ *larkhanaensis*, d'Arch.
„ sp.
Cardium triforme, C. Sow.
Pectunculus pecten, C. Sow.
Pecten bouei, d'Arch.
„ sp.
Ostrea multicostata, Desh.
Spondylus rouaulti, d'Arch.
Placuna, sp.

ECHINODERMATA.

Schizaster granti, Dun. and Sla.
Euspatangus patellaris, d'Arch.
Clypeaster depressus, C. Sow.
Temnechinus costatus, d'Arch.
„ *rousseaui*, d'Arch.
Temnechinus tuberculosus, d'Arch. & Haim.
Temnechinus affinis, Dun. and Sla.
Cidaris depressa, Dun. and Sla.
„ *granulata*, Dun. and Sla.

POLYPES.

Several corals undetermined.

The fossil Echinoidea of the Káthiáwár collections have lately been examined and described by Professors P. Martin Duncan and W. Percy Staden.[1] Besides those enumerated in the above lists, the collection comprises a specimen of *Cœlopleurus forbesi*, d'Archiac and Haime, from near Gága; a new genus *Grammechinus* (*G. regularis*), Duncan and Sladen, from near Lowaráli, in Oka Mandal; a *Brissopsis*, sp. indet., two miles north of Visáwára, and *Breynia carinata*, d'Arch. and Haim., bringing up the total number of species to thirteen (all of miocene age), of which six are common to Cutch and Káthiáwár.

At the same locality in Oka Mandal with *Grammechinus regularis*, were found *Pecten soomrowensis*, C. Sow., *P. favrei*, d'Arch., *P.* (*Vola*) *sub-corneus*, d'Arch. and Haim., and casts of spirals.

The scarped hill ridge on the north side of the Bhogát creek mouth is formed mostly of Gáj beds; here also the above three species of *Pecten* occur, together with a small stunted variety of *Ostrea multicostata*, *Arca peethensis* (?), d'Arch., and *Dosinia pseudo-argus*, also fragments of a small crab, spines of *Cidaris*, and bryozoa, &c. Again, two miles north-west of Bhogát village, similar fossils were obtained, together with *Tellina exarata*, C. Sow., *T. subdonacialis*, a *Spondylus*, and a *Placuna*; *Trochus loryi*, d'Arch. and Haim., *Cerithium rude*, C. Sow., *C. corrugatum*, *Ranella viperina*, d'Arch. and Haim., and *Strombus gigas*. The fossils are mostly casts, and they are frequently crowded together in parts of the rock.

Foraminifera in beds near Bhogát.

Certain of the beds exposed in a few places in the neighbourhood of Bhogát,—as, for example, a pale yellowish shaly marl in the stream bank two miles to the north-east of that village,—contain small foraminifera and other organisms, among them a *Conulites* (or *Patellina*?), which is not unlike a nummulite in shape, though differing in structure; and very probably the discovery of this foraminifer gave rise to the presumption that rocks of nummulitic age had been found in the province.

[1] Palæontologia Indica, Series XIV, Vol. 1, part 4, pp. 80-91.

Many masses of weathered-out coral lie scattered about the surface of the rocky ground between the villages of Nandána and Rán, indicating a coral zone not far above the local base of the group.

Coral zone.

Several small corals were also obtained from a ferruginous bed resting immediately upon, and abutting against, the flank of one of the lateritic ridges on the north side of Nandána (near Bhatia).

In the Gáj area along the west side of the *ran* separating Oka Mandal from the mainland, a remarkably large variety of *Ostrea multicostata* occurs in soft arenaceous clays, exposed in the bank of a creek-like recess east of Lawaráli; and tubes of *Kuphus rectus* were found in the soft clay-marl of the scarp above the bank.

Dwárka beds.—This group comprises rocks of very various lithological character; and though the total thickness is inconsiderable, it may be possible eventually to divide the beds into sub-groups, or to mark off some of the later deposits as pleistocene. The short time at my disposal, towards the close of a long field season, did not admit of a very close examination of these rocks. They are, for the most part, unfossiliferous, though some beds are composed almost entirely of organic fragments (pounded shells, corals, &c.), but the few recognizable fossils are not sufficiently characteristic to determine the relative age of the several deposits.

The lower beds of the group are yellow, soft, and earthy, or clayey and gypseous in part; sometimes strongly stained by iron, with a few thin bands of harder rock. I have separated these beds from the Gáj group, on account of the marked change in appearance and mineral character, and the absence of any Gáj fossils; indeed, no fossils at all were obtained, except from a concretionary gritty band, in the neighbourhood of Gága, in which a small peculiar *Pecten*, unknown in the lower group, is rather abundant.

Reasons for separating them from the Gáj.

The reddish-yellow soft, earthy or marly clay beds occupy the low-lying parts of southern Oka Mandal, and extend away to the south-east, into the low hills near the coast.

Limestones variously coloured.

Another set of beds, occupying the higher parts of southern Oka Mandal, and spreading throughout the north, consists of limestones more or less marly and arenaceous, seldom very compact, more generally porous and slightly adhering to the tongue; they occur as thick flaggy beds, some of which are made up almost entirely of small organisms (foraminifera), with the interspaces filled with crystalline matter (calcite). In colour the limestones are light and dark buff, very pale grey, pinkish yellow, ochreous, and dark yellowish-brown; the brown bed is a semi-crystalline compact rock; it occurs in the neighbourhood of Dhenki above the light-coloured beds.

In Beyt Island, and along the northern coast of Oka Mandal, light-coloured marly clays, and finely arenaceous marlstones prevail; together with slightly standy limestone, with crystalline texture; and a calcareous fine-grained sandstone.

Limestones and marls at Positra and Mulwásar.

A close pale buff limestone, more or less marly or crystalline, and rather arenaceous, extends over the surface of the country at Positra in the north-east corner of Oka Mandal, passing down into soft earthy marls. It also prevails on the higher parts southwards, to beyond Mulwásar, where the limestone is seen to rest upon a rubbly bed of nodules of marlstone in soft earthy marl, below which are soft clays and marls varying from a rich yellow to a pale-whitish colour. There are also bands of fine sandstone and sandy limestone among the lower beds. The pale buff limestone frequently contains hollow casts of some branching coral, or bryozoon, quite indeterminable, as the cavities are lined and partially filled with calcite, which has obliterated all structure.

Coast-fringing rocks.

A set of rocks, seldom met with at any great distance from the coast, and which I have tentatively included within the upper limit of the present group,—in the absence of distinct evidence to the contrary,—may, as already intimated, be eventually regarded as of post-pliocene age. These may be designated as the 'coast-fringing rocks.' They consist of porous, open, or in part

compact limestones, of pale-yellowish colour, gritty with quartz grains, and finely crystalline.

Dwárka cliffs.

These rocks form the low cliffs at Dwárka, and extend for some way along the coast; they also form an outlying ridge of hill about five miles inland from Virwála, bearing from the village of Dhrásanvel northwards through Gadechi towards the low country around Arámra, at which place the limestone is also met with at nearly sea-level. It is less porous and more sandy at this latter locality, where it has been much used for building. That of the outlying ridge is very open, from the dissolving out of the contained organic fragments; it is also false-bedded, and not uniform in texture. Occasionally a badly preserved fossil is seen; a coarsely-ribbed *Pecten*, somewhat resembling the living *P. pyxidatus* was obtained, but too much worn for distinct identification.

The cliffs at Dwárka show about 20 to 30 feet of beds varying from impure limestone to rag-stone; near the top of the section the limestone is purer, though still gritty with quartz grains, and containing shelly fragments, among which those of *Balanus* prevail. All these beds are obliquely laminated, or cross-bedded, indicating a shallow littoral sea for their deposition.

Sub-recent and Alluvial deposits.—Under this heading is included a variety of deposits, marine, estuarine, freshwater, and subaërial. Among the former are—the miliolite, which sheets the south-eastern margin of the peninsula, and is found in residual patches on the hills of the interior; the raised beaches and consolidated shore sands prevalent along the south-western seaboard; raised coral-reefs bordering the Gulf of Cutch; and marine concretes—with oyster beds now far from the sea,—that extend beneath the alluvial soil almost throughout the northern plains, and are exposed along the margin of the Ran of Cutch.

Sand dunes.

Among the æolian, or subaërial accumulations, the sand dunes, bordering the Ran, and in many places along the sea-margin, take precedence: while desert sand occurs on some of the plains in the northern part of Káthiáwár.

Ordinary alluvial plains prevail along the eastern limit of the province, and extend into the basin of the Sábarmati river.

It will be seen, by a reference to the map, that the belt of alluvium, which commences at Gopnáth Point near Dáta, is continuous westwards round the coast, gradually widening in the southern part, but becoming somewhat contracted in the neighbourhood of Charwar. Shortly beyond this, it expands into extensive plains and low *ran*-like flats of saline waste ground, up to the latitude of Porbandar. Thence the belt is no longer persistent; there being only a narrow strip of sub-recent deposits along the coast, with occasional inlets of low flood-land and marshy alluvium.

Miliolite.

A large portion of the area indicated above as alluvial is occupied by miliolitic limestone.[1] This rock is a finely oolitic freestone, almost free from sand or other foreign particles; the nuclei of the oolite grains are mostly organic. The minute foraminifer of each grain, though not apparent in the crude state, may be readily detected with a lens after treatment with dilute acid. The rock is thin-bedded, with strong oblique lamination. The farther it occurs from the coast, the purer is the limestone; whilst that along the seaboard is not unfrequently mixed with much sand.

Miliolite forms the bluffs and cliffs on the south-eastern coast, and extends some way inland, sheeting the surface of the country. In many places it overlaps the tertiary rocks, and is seen to rest upon the laterite and trap. In the eastern part of the alluvial area, it is seen only near the coast; while, to the westward, the whole country is encrusted with the rock. The streams in this ground have cut through it, forming small 'cañons' that are often impassable for many miles.

The cliffs of Diu island are 50 feet high, and there are quarries in the interior equally deep, which have not pierced through this peculiar rock. At Jáferábád the cliffs rise to 100 feet, and again at Gopnáth they cannot be much less, but the section at the two latter localities is not made up entirely of the limestone. There are light-grey calcareous sandstones,

[1] I have indicated the presence of the miliolite by fine transverse blue lines on the map.

indifferently cemented, associated with the miliolite, and passing the one into the other. At Gopnáth, some of the beds in the section are earthy and rubbly, being in part largely made up of nodular concretions In some of these impure miliolitic beds, a few fresh-water shells have been found from time to time; the following five species of existing land shells were noted by Mr. Theobald in 1858,—*Bulimus insularis*, *B. punctatus*, two *Helices*, and a *Cyclotus*.

Land shells in the miliolite.

It is not unreasonable to expect that such light shells would be floated down by small streams or floods, and become entombed in a marine littoral deposit, which this evidently is.

At Mota Kotra, on the coast south of Dáta, there are overhanging cliffs in which a mass of grey softish calcareous sandstone is seen resting upon miliolite limestone, and having a similar limestone above it. The grey sandstone, though unbedded, is laminated obliquely in various directions, after the manner of blown sand; and it seems probable that much of the grey slightly coherent sandstone consisted of blown sand, in the form of dunes that became submerged; and the sand partially cemented by percolation of lime from the miliolite beds.

Blown sand interstratified.

The subrecent rocks all along this part of the coast, from Gopnáth downwards, are similarly constituted. The cliffs at Gadhara, south of Mowa, which are about 70 feet in height, well exemplify the irregular mode of their accumulation.

Along the south-west coast in the neighbourhood of Pátan Veráwal and Mangrol, the sub-recent sandy beds are stronger, and represent a littoral accumulation, or raised beach; for, at one place, I obtained many well-fossilized shells, such as *Conus*, *Cypræa*, and several Pelecypoda. The harder portions of this rock, not always on the same horizon, have been largely quarried for an inferior building stone, while other portions of it are still incoherent. The upper part, which contains the shells, is coarse-grained and softish.

Raised beach on south-west coast.

At Verāwal a variety of miliolite is quarried, in enormous masses, for the break-water. It is a fine-grained close white rock, though much honeycombed, averaging about three feet in thickness. It rests, with an earthy parting, upon a darker and more compact, though much worn and perforated, limestone, which passes down into a concretionary, impure sandy limestone; this latter is, in part, a mass of nodular concretions. In another quarry near by, a compact, whitish, finely-speckled miliolitic limestone was observed to pass laterally into an open porous sandy-looking rock—though made up very largely of organic fragments and minute organisms—which much resembles the raised shore rock mentioned above.

Miliolite used for Verāwal break-water.

The miliolite of the interior occurs capriciously in the gorges of the hills, or as patches on their sides, like remnants of a snow drift; and, though conspicuous enough in the field, these restricted patches could not be indicated except on a large-scale map. The rock is extensively used both as a building stone and for making lime.

The conical hill of Chotila, that gives its name to the *thána* and large village on the high road mid-way between Wadhwán and Rájkot, is the highest point in all northern Káthiáwár. It is recorded as being 1,173 feet above mean sea-level, and is about 550 feet higher than the surrounding plains. The hill is of trap, with a nether foundation of sandstone, as described in a previous page; but in the fringe of miliolite which occurs around its truncated top, there is conclusive evidence that this hill, and consequently all the surrounding country, has been beneath the sea within comparatively recent times. Probably the greater part of the peninsula was depressed at least 1,170 feet lower than it stands at the present day.

Miliolite on Chotila hill.

Extensive rock plains are a peculiar feature in the western parts of Káthiáwár, more particularly in the Dhrol and the Nawánagar States. The rock of these parts is bedded trap, mostly decomposed and crumbling. Yet the surface of the country is almost as level as that of an alluvial plain. The planing down of such material could not have been effected by subaërial denu-

Rock plains.

dation, and, I conclude, could only have been produced by a gradually encroaching sea,—presumably the waters that have left their limit-mark in the miliolite on the hills of the interior.

The Ran.

The Ran of Cutch (or Little Ran in contradistinction to the Great Western Ran) as the low-level waste to the north of Káthiáwár is called, was doubtless, at no very distant date, a shallow gulf, or arm of the sea,—an extension of the present Gulf of Cutch, which itself is now very shallow,—and, being elevated with the general upheaval of the district, became silted up by the accumulation of mud (clays) brought there by streams from the surrounding lands.

The surface soil of the Ran is mostly a yellowish drab clay, with strong saline efflorescence, or a powdery surface, such as is seen on the '*reh*' ground of other parts of India. At the salt-works near Kúda (or Kúra) within the Dhrangadra State, and about 65 miles from the head of the Gulf of Cutch, the section in the brine pits is as follows (descending) :—

1. Surface soil of saline earthy clay.
2. '*Kholia*' (or '*Korea*'), a dark earthy plastic clay.
3. '*Soneo*' (or '*Honeo*'), a brown clunch, a close stiff clay.
4. '*Lilera,*' a dark bluish, saline plastic clay with imbedded crystals of gypsum, hollow casts of decomposed vegetable fibre (? rootlets), and many small shells.

The base of No. 4 was not reached in the brine-pits, which are about 10 or 12 feet in depth; neither was it possible to determine the thickness of the several beds of clay, as the wicker-work protecting the sides obscured the section.

The *soneo* clay (No. 3) is impervious to water, and almost free from salt; the brine is obtained from the bed below.[1] The following is a provi-

[1] The brine is baled out and run into 'pans,' or shallow rectangular floors, where it is allowed to concentrate by natural evaporation, when the salt crystallizes in segregated lumps, and the remaining liquor is run off. The best salt is that crystallized in half-inch cubes. The salt is stacked in large heaps, exposed to all weathers. Some of the heaps had been there for seven years, and apparently little the worse for the exposure.

sional list of the little shells from the *lilera* clay (No. 4), after a preliminary examination of them by Mr. G. Nevill (late of the Indian Museum), who has kindly taken them in hand for determination and description :—

Iympanotomus fluviatilis.
Pirenella caillandi (and *layardi ?*).
Assiminea (sub-gen. of *Rissoa*), sp.
A new sp. of *Rissoidæ-Fairbankia feddeni*, Nev.
Stenothyra, two sp. (*minima*, and var. ? new sp.).
Melampus striatus, var. *microsculpta*, Nev.
Probably a new sp. of the rare gen. *Theora.*
Glaucomya (*Glauconome*), near *chinensis.*
Besides three or four others not determined.

A deserted extension of the gulf.

It will be seen that the collection, though small, is of some interest to the conchologist, as well as to the geologist. The general facies presents a mingling of brackish water with marine forms; and, in connection with the fact that the locality is situated 65 miles from the present head of the gulf, bears out the hypothesis already stated, that the Ran had been an annexe of the gulf not so very long ago, which, as the salt water receded, became silted up.

Alluvium near the Ran.

A belt of alluvium, mostly sub-aërial, extends along the northern limit of the Káthiáwár peninsula: its outer margin, forming the southern coast line of the Ran, is in many parts loaded with sand dunes (raised by the prevailing wind from W.S.W.). The belt varies in width from two or three miles at Kúda, to about sixteen miles in the Mália district; while, in the east, it widens to six or seven miles, and, sweeping round the jurassic rock area of Dhrangadra, spreads out into far-reaching plains, which extend into the Ahmedabad country.

Older alluvium.

Along the inner margin of this alluvium, there are sundry accumulations which I regard as older alluvium. They are more consolidated than the later deposits, and in many places yield a fair building stone. The surface of these older

alluvial rocks shows wear and denudation in some parts of the field, and are even occasionally heavily conglomeratic.

Coral reefs in Gulf of Cutch.

Raised coral reefs and oyster beds.—The whole of the sea-board facing the Gulf of Cutch from Nawánagar westward, including the islands off the coast, is fringed with dead coral reefs: the surfaces of which are much exposed at low spring tides. In some places the coral floor extends inland up to high tide level, as a Saláya, the *bandar* for the town of Khambhála. The coral has a very fine and uniform texture, and has been worked as a substitute for stone for building, but not with very satisfactory results owing to salt impregnation.

The existence of these dead coral reefs is, of course, a proof that the country has been rising during late times.

Dead oyster beds indicating upheaval.

A further instance of the rising of the peninsula is seen in the occurrence of dead oyster beds in the Mália district, some way above the head of the gulf. One of these dead oyster beds may be seen in the bed of a stream two miles north of Mália, 15 miles from the nearest sea-coast, and five miles from the highest spring-tide mark. A second locality is to the east of Mália, where the oyster bed is exposed along the banks of a small stream course near the village of Chikli. This site is 22 miles in a bee-line from the present sea-coast, and about ten miles from the highest spring-tide mark. There are at least two large species of *Ostrea,* one of which is identical with the edible oyster of the south coast. The associated rocks are sub-recent concrete imperfectly cemented, and gravel beds. Both the localities mentioned are within a mile and a half of the Ran.[1]

Soil.

The soil of the plains is very shallow; and varies from black cotton soil, where the floor is of trap, to a light sandy one when resting upon sandstone. The eastern side of any extensive spread of the latter is almost wholly of pure sand, accumulated in that direction by the prevailing westerly winds.

[1] Some marine shells, of sub-recent date, were also collected from the surface of the Ran in this locality.

CHAPTER III.

GENERAL SUMMARY.

The oldest rocks in the country, the Umia sandstones, cannot be placed lower in the geological scale than the uppermost division of the Gondwána system of peninsular India; they occupy a subordinate area in the northern part of the province. Upon them rest other sandstones and grits, with a meagre development of limestone; these upper beds may be regarded as the remains of a newer group than the Umias; and they probably belong to an early cretaceous age. The trappean system is next represented by a very extensive and thick series of volcanic products; which, by their extraordinary display of flow and dyke features, indicate, more especially than in any other part of India, a period of great fissure eruption.

In the latter part of the trappean period it would appear that the eruptions became more local and restricted to certain centres of issue, assimilating more to the nature of volcanoes, as illustrated in the Junágarh and the Barda hills. Some time subsequent to the fissure-eruption period the surface of the country became subject to a great amount of denudation, in some parts more than in others. In the northern division, for instance, the traps have been entirely denuded, laying bare the cretaceous and jurassic sandstones that have themselves also undergone much scouring and partial removal. About this time the lower half of the province was depressed to a certain extent, bringing the southern margin of the traps beneath the sea, and then tertiary strata of miocene age were deposited as a littoral fringe upon the submerged portion of the traps. The south-western part appears to have remained under water longer to admit of later accumulations upon the miocene rocks. After the depression a period of elevation set in; but at a later date, *i.e.*, in sub-recent times, nearly the whole province was again dipped beneath the sea—only the tops of the highest hills probably escaping submersion; and on its final elevation the receding waters left their mark in the patches and fringes of white miliolite now seen on the sides of the hills and in

recesses of the ravines. It seems probable that the Ran was deserted by the sea towards the close of this last elevation. It is not yet known that the upward movement has altogether ceased; bench-marks were, however, laid down by Captain Baird, R.E., of the Trigonometrical Survey, in 1873-75, to ascertain the rise or fall of the land; but as yet sufficient time has not elapsed for testing the change.

CHAPTER IV.

ECONOMIC PRODUCTS.

Minerals.

Coal.—As has already been stated, when treating of the Umia rocks, thin strings of coaly matter, in a band of carbonaceous shale, near Thán, north of Chotila, have given rise to frequent reports of the existence of coal in this province. I can only repeat that this deposit is not worthy of the name even of 'fuel,' as it will not support its own combustion.

Iron.—This metal was formerly worked to some extent in many parts of the province. At Kantrori, near Sara, in the north, there are very large refuse heaps of iron-slag, indicating a considerable industry now abandoned. The ore was doubtless obtained from the ironstone bands near the top of the Umia group.

In the west, the lateritic rocks have yielded very rich iron ore; near Bákharla, not far from Porbandar, a number of small pits, 5 to 15 feet deep, have been sunk in the laterite to obtain the ore; and, again, at Pálakra, further to the north, there is evidence of a past industry in this metal. The mines have not been worked by the present generation, and to-day there is not a furnace in the province. The scarcity of fuel, and the cheapness of the imported metal, have been the cause of the indigenous manufacture dying out.

Magnetic iron sand.—A black sand, used by clerks and others as a blotter, is found in two or three places on the shore south of Gopnáth Point. It consists mostly of magnetic iron derived from the traps.

Lead and copper.—Within the Gir hills, at a site called Bánej-nes, on the Machundri stream, that flows past Una, some galena, associated with copper pyrites, occurs very sparingly in a quartz vein in the trap rocks. The vein, which bears about north-15°-east, and south-15°-west, is only a few inches (2″ to 6″) in width where exposed, and it could not be traced for many yards, neither do the ores prevail throughout its course. I do not, therefore, consider there is any promise of a workable quantity of ore being found in the place. The uncommon occurrence (in India) of a metalliferous vein in the trap rocks is worthy of note.

Lime.—The miliolite, wherever procurable, is largely used for making lime. At Dhrangadra a thin portion of limy earth among the sandstones quarried for building is carefully collected and kilned, as it is the only source in that part of the district. At Múli and other places a kankary deposit at the base of the traps is used for local purposes.

Gypsum.—This mineral occurs in some of the tertiary beds in the Bhávnagar State, near Nandána in the western part of Halar, in the hills about Kuranga south of Oka Mandal, and one or two other places, as small tabular masses and crystals of selenite, scattered through the clays; but scarcely in sufficient quantity or purity to be of much commercial value. At Bhávnagar, however, it is kilned and used by the State Engineer for moulds and model castings.[1]

Moss-agate.—At Khijaria, a village 2½ miles west of Tankára, in the Morvi State, some moss-agate, occurring as a large irregular vein in decomposed amygdaloidal trap, has been worked in a desultory way, by the villagers, for a number of years. The agate is purchased by native traders from Bombay. A royalty of two rupees per *maun* is levied by the State. Amythistine quartz and clear rock-crystal are occasionally met with in the workings.

Building and Ornamental Stones.

Miliolite, which is a finely oolitic and highly organic porous limestone, is extensively used as a building stone for Hindu temples,

[1] The tertiary beds of Cutch would yield a much greater supply of gypsum in large clear crystal and tabular masses, more especially in the western part of that State, south of Lakpat.

bridging the smaller streams, and ashlar work generally. It is a most useful stone, being readily worked : it can be faced with an axe, and the chips and rubble burnt for lime, the quality of which is said to be excellent.

This stone is exported in large quantities from the port of Porbandar to Bombay and other places, and has hence gained the well-known name of 'Porbandar stone;' the quarries, however, whence it is taken are situated along the western base of the Bárda hills, about 9 miles north-east of the port. The deposit there is very thick, and occurs in three parallel ridges, or ledges, rising one above the other; it is white-coloured and very obliquely laminated at an angle of about 22°, varying in different quarries. The miliolite extends out into the plains around Adatiána and Ránáwu.

A much inferior stone has been largely quarried at Porbandar itself, from a very open imperfectly cemented shore deposit, or raised beach; this doubtless has often been palmed off as genuine Porbandar stone. The effect of rain and weather on miliolite is to harden it and render it less porous.

Dhrangadra stone.—There are extensive quarries in the neighbourhood of Dhrangadra, the chief town of that State. The stone is renowned throughout, and beyond, the province: a quantity of it having even been carted as far as Bhooj in Cutch, for the Rao's new palace. It is a light-coloured open-grained slightly kaolinic sandstone, very cross-bedded, with oblique lamination; varying in texture (even in a hand specimen) from fine-grained to coarse and gritty, and in colour from white to pale pink or yellow. The stone has been employed largely in masonry at Dhrangadra: it was exclusively used in building the new court-house, the palatial gateway, with clock-tower, the school-house, &c. The finer varieties admit of rough carving for ornamental work.

Near Baoli, a village six miles south-west of Dhrangadra, a bed of sandstone of remarkably fine texture and even lamination is quarried and used as a whetstone: it is also worked for ornamental purposes, carved into platters, cups, and water-vessels, being sufficiently porous to act as

a refrigerator. Pipe-bowls, for opium-smoking, are also cut out of this stone.

Marble.—In 1878 it was reported to me that statuary marble 'in any quantity' had been discovered in the Gondal State, and that quarries had been opened in it. The so-called 'marble quarries' proved to be some very limited surface diggings along an irregular vein in the trap rocks, near the villages of Khírasra and Sejriála in the Bháyáwadar *pargana*, about 15 miles north-west of Dhoráji. The vein is not more than about 30 inches in width, often less; and the marble is associated with quartz and other spars, such as coarsely crystallized calcite (calc-spar) of which the vein is largely made up in places. The workable stone is a white-mottled hard marble, capable of a high polish, and consists of a mingled combination of aragonite and calcite. I do not consider it could be worked profitably for exportation, but it might be locally employed for ornamental purposes in a small way.

The stone is interesting from a mineralogical point of view: it is decidedly harder than ordinary white marble, and somewhat heavier; neither has it any distinct rhombic cleavage. Mr. Mallet has determined it to be "remarkably pure carbonate of lime, without any appreciable quantity of either iron or magnesia." Its specific gravity is 2·87 (which is higher than any calcite, and a little under ordinary aragonite). Its hardness (3·5—4) more nearly agrees with aragonite. When strongly heated, before the blow-pipe, it does not fall to pieces like aragonite, but becomes opaque and more readily friable than ordinary white marble after being similarly heated.

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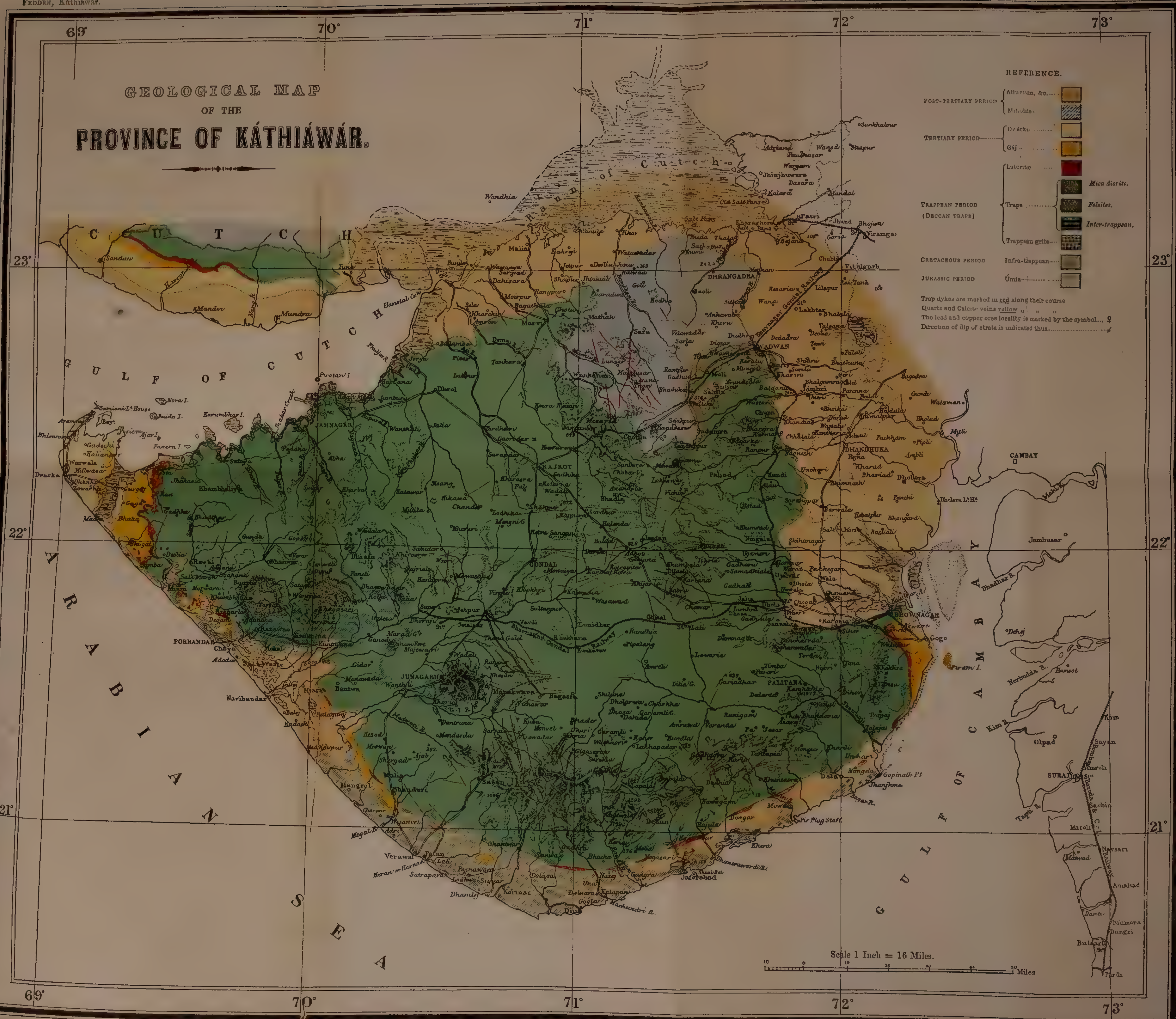
GEOLOGICAL MAP
OF THE
PROVINCE OF KÁTHIÁWÁR.
REFERENCE.
POST-TERTIARY PERIOD
Alluvium, &c.
Miliolite
TERTIARY PERIOD
Dwárká
Gáj
TRAPPEAN PERIOD
(DECCAN TRAPS)
Lateritic
Traps
Mica diorite.
Felsites.
Inter-trappean.
Trappean grits
CRETACEOUS PERIOD
Infra-trappean
JURASSIC PERIOD
Úmia
Trap dykes are marked in red along their course
Quartz and Calcite veins yellow " " "
The lead and copper ores locality is marked by the symbol
Direction of dip of strata is indicated thus
Scale 1 Inch = 16 Miles.
Miles
C U T C H
GULF OF CUTCH
ARABIAN SEA
GULF OF CAMBAY
Rann of Cutch
JAMNAGAR
RAJKOT
GONDAL
JUNAGARH
PORBANDAR
BHOWNAGAR
DHRANGADRA
WADWAN
DHANDHUKA
PALITANA
CAMBAY
SURAT
Dwarka
Verawal
Diu
Gogo
Morvi
Wankaner
Jetpur
Dhoraji
Amreli
Mandvi
Mundra
Jambusar
69°
70°
71°
72°
73°
23°
22°
21°

MEMOIRS

OF

THE GEOLOGICAL SURVEY OF INDIA.

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THE CENTRAL CONE OF BARREN ISLAND

Printed at Geol: Survey Office.

(*From a photo: by C. F. Wight, Indian Marine: positive by Messr. Woodcroft & Co.*)

In February 1884, Captain Hobday and I visited the islands in the Government steamer 'Celerity,' commanded by Captain Edwards, and spent nine days at Barren Island and four at Narcondam. During that time Captain Hobday constructed maps of the volcanoes on the scale of 8 inches to the mile, of which copies, reduced to the scale of one-half, are herewith appended. The results of my geological work are embodied in the following pages.

The last recorded visit previous to ours was made in 1873, by Professor V. Ball, late of the Geological Survey of India. In his account of Barren Island [1] attention is called to the erroneous idea that the sea surrounds the inner cone, which seems to have originated with Von Buch, and to have been accepted on his authority by various other authors. Although the misconception on this point had been previously pointed out by Dr. Liebig in 1858,[2] and by the Rev. Charles Parish in 1862,[3] it has been repeated in text-books of geology published within the last few years. Full references to previous accounts, and a *précis* of the information contained in them, are given by Mr. Ball, so that it is unnecessary for me to allude to them further here, although I shall have occasion to cite them frequently in the following pages.

Barren Island and Narcondam situated on the Sunda zone of volcanic energy.

Barren Island lies approximately in N. lat. 12°-15′, E. long. 93°-50′, and Narcondam in N. lat. 13°-26′, E. long. 94°-15′. Most writers on vulcanology have regarded them as seated in the continuation of that great zone of volcanic energy which stretches for some 2,000 miles along the Sunda group of islands, the terrible activity of which has been recently illustrated by the explosive eruption at Krakatau. Some authors, Mrs. Sommerville and Scrope amongst others, consider that the extension of the same zone is to be found in the islands of Arakán, some of

Northern extension of the zone.

[1] Records, Geol. Surv. India, Vol. VI, page 81; also Geol. Mag., Lond., 1879, Vol. VI, page 16.

[2] Selections from the Records of the Government of India (Home Department), No. XXV, page 124; republished in J. A. S. B., Vol. XXIX.

[3] Proc. Geog. Soc., Lond., 1862, Vol. VI, page 216.

which, especially Rámri and Cheduba, contain mud volcanoes, from which violent eruptions, accompanied by outbursts of flame, have frequently taken place during the last half century.[1] Mr. W. T. Blanford has recently dissented from this view on the ground that the mud volcanoes have "not the slightest connection with any real volcanic action,"[2] and has suggested that the continuation of the zone in question should be sought in the extinct volcano of Puppa, in Upper Burma, and another similar volcano near Momein in Yunnan. In a previous paper, however, I have expressed the opinion that, although the mud volcanoes in question are non-volcanic in the sense that none of the products of eruption have undergone fusion, and that the motive force is mainly gas, not steam, they still are due to volcanic heat of a low degree of intensity. The rocks of the Rámri group of islands are lignitiferous and petroleum-bearing. Similar rocks occur over large areas in Burma and Assam, yet it is only in the Rámri Islands that fire-emitting mud volcanoes are known. The explanation of this peculiarity that I have suggested is, that the islands being situated near the extremity of the Sunda zone of volcanic energy, the subterranean heat, although insufficient to fuse the rocks and produce volcanic phenomena in the ordinary sense of the term, is still sufficient to produce destructive distillation of the lignite, resulting in the formation of the quantities of inflammable gas which constitutes the motive power of the mud volcanoes, and which, on bursting forth, rises in flames, sometimes to a height of several hundred feet.[3] I conceive that the heat attains a local maximum in the neighbourhood of Rámri, while it is lower on the Arakán coast to the north and south, just as the heat of a far higher degree of intensity has attained a local maximum at Narcondam and at Barren Island, while between these, and between the latter and Sumatra, it has not risen sufficiently high to produce true volcanic phenomena (above the sea-level at least). Two (undoubtedly mud) volcanoes are said

[1] The earlier observers in Rámri and Cheduba mistook the mud volcanoes there for real volcanoes, and by their accounts Scrope, Daubeny, and others, were led astray.

[2] Manual of the Geology of India, part 2, pages 725, 730.

[3] Records, G. S. I., Vol. XI, page 203.

to have opened in the Chittagong district at the time of the great earthquake of 2nd April 1762,[1] so that there may be a local development of heat there also, although less marked than that at Rámri.

BARREN ISLAND.

General appearance.

On approaching Barren Island from Port Blair, or indeed from any direction but the west, one might naturally be puzzled as to how it came to acquire its name, the outer slopes of the island being covered with dense tree jungle from near the sea-level to the summit. Only here and there do large patches of grass appear, while of bare rock there is almost none, save where the lava has been eaten backwards into cliffs along the surf-washed coast. On the western side of the island there is a deep breach, giving entrance to the interior, where one finds oneself in the midst of an almost circular (slightly oval) amphitheatre about a mile in diameter. Towards the south-east the declivities, rising to a height of seven or eight hundred feet above the floor of the crater, or some 1,100 above the sea, are well wooded, except where the walls of lava are too precipitous to afford any footing to vegetation. On the north the slopes are much less steep and high, with a rounded outline towards the top, and are largely covered with loose, black, naked ash.

In the midst of the amphitheatre rises the central cone to a height of about 1,000 feet above the sea, with, as seen from the west, an almost perfectly symmetrical outline, the sides preserving an even slope of 32°. Scarcely a blade of vegetation is to be seen on the dark ash which covers the surface. The truncation at the summit marks the site of the crater, and here a thin column of steam rises slowly into the air.

Almost encircling the base of the cone are streams of lava, one of which has poured through the breach into the sea, and all covered with a rugged, black, and scoriaceous crust, the fissured and hummocky surface of which cannot be traversed without difficulty, and which is almost absolutely bare of vegetation.[2]

[1] J. A. S. B., XII, p. 1050.

[2] Standing on the ash slopes to the north of the cone, and looking down on the lava streams, one is reminded, strange as it may appear, of some snowy Himalayan pass. The

The frontispiece, copied, with Mr. Jules Schaumburg's usual artistic skill, from a photograph taken during our visit by Mr. C. F. Wight, 2nd officer of the I. G. S. 'Celerity,' gives a very good idea of the central cone and the lava streams at the base. The point of view is a slight eminence about 200 yards south of the hot spring.

The ancient cone.

As mentioned above, the great crater is about a mile in diameter, the diameter of the island, which is not far from circular, being about twice as much. The external slopes are naturally longest on the side where the edge of the crater is highest, and, in consequence of this, the centre of the island does not quite coincide with the centre of the crater.

Inequality of the N.W. and S.E. sides of the crater.

This leads to the question why one side of the crater is higher than the remaining portion of the circumference. It is well known that cones formed mainly of scoriæ, &c., are often highest on the side to leeward with respect to the prevalent wind, but the peculiarity in question, if due in any degree to this cause, can only be so very partially and indirectly. The prevalent winds in the region under discussion are the south-west and the north-east monsoons, the former blowing for six months of the year, and with considerably more force than the latter, which blows for the remaining six.[1] There would be a tendency therefore for the fragmentary ejecta to accumulate, during the course of ages, most abundantly on the north-eastern side of the volcano, with a minor accumulation to the south-west, and a minimum quantity on the intervening portions.

rugged streams of lava which have poured down the valleys bear no slight resemblance in general form to a bifurcating glacier with its moraine-covered and fissured surface, while the ash slopes, formed, as they have been, like those of snow, by particles of matter falling through the air, preserve very similar contours. Looked at with a not too critical eye, the black and white products of heat and of cold bear somewhat the same relation to each other that a negative photograph bears to the positive.

[1] The mean velocity of the wind at Port Blair during the south-west monsoon is rather more than 1½ times that during north-east (Report on the Meteorology of India in 1882). The pressure, therefore, which varies as the square of the velocity, would be about 2½ times as great.

But such lava streams as issued from the main crater (and not from lateral vents on the slopes of the mountain) would overflow, or break through, the lowest part of the rim, thus tending to neutralise the inequality just mentioned, and the greater resistance that the solidified lava would doubtless present to subsequent pluvial denudation,[1] would be another element tending in the same direction. Again, the rain during the south-west monsoon must, owing to the influence of the wind, fall in a more or less oblique direction, the result being a heavier rainfall, and consequently greater denudation, on the windward than on the leeward outer declivities of the mountain; the reverse being the case with reference to the slopes of the crater itself. The interaction of these, and perhaps other, causes, has been such that the resultant does not admit of being traced with any certainty. It may be, indeed, that the superior height of the crater rim towards the south-east is due in some degree to a more than average proportion of lava there, and the section exposed along the precipitous cliffs certainly does show such rock to be strongly in the ascendant. But any such excess, if real,[2] and due to the causes just mentioned, ought to be accompanied by a corresponding excess towards the north-west, where, however, the crater rim is lowest.

The marked deficiency in height of the north-western half of the circumference must then be ascribed to some other origin. A shifting of the axis of eruption would tend to produce the feature in question; that is to say, if the axis during the explosive eruption by which the ancient crater was in all probability formed, was somewhat to the north-west of the axis eisting during the time the original cone was built up, the north-western side of the cone would be blown away to a greater

[1] The very perfect preservation of the extinct scoriæ cones of Auvergne has been ascribed to the rain sinking into the porous material as fast as it falls, so that there is no surface wash. No doubt the ash of Barren Island is preserved in a similar way, but far less completely, owing to the heavier rainfall, which at Port Blair, the nearest meteorological station, and 70 miles to the south-west, is 118 inches per annum. Of this, about 100 inches falls during the six months of the south-west monsoon.

[2] The concealment of the outcrop of the older rocks elsewhere, by the most recent ash, prevents any comparison being made.

extent than the south-eastern. But there is no corroborative evidence tending to show that any such change of axis has ever taken place, and I believe the peculiarity under discussion should be ascribed mainly, if not entirely, to a bodily subsidence of the north-western half of the volcano.

Most probably the ancient crater was originally formed by the blowing away of the upper and central part of the cone by a great explosive eruption[1] (since which time the crater has been modified, and enlarged, by denudation), and the subsidence just referred to was very probably a concomitant feature of the same catastrophe. A parallel instance, on a far greater scale, may be found in the explosive eruption of Krakatau on the 27th of August 1883, when the entire northern part of the volcano, about 9 square miles in area, and comprising two-thirds of the whole island, sank and disappeared beneath the sea.[2]

Original height of ancient cone.

It is a question of some interest what the original height of the volcano was before the blowing away of the upper part. Most sections of the inner cone present an angle of 32°, but the average slope of the outer cone is distinctly lower, not exceeding about 25°; this may be caused in part by a central subsidence of the volcano, due to the weight of the continually increasing mass of material, a kind of subsidence which has been recognised in the case of other volcanic mountains[3]; but I am inclined to think that it is mainly due to the flows of lava, which constitute so large a portion of the material of the outer cone, having solidified at a lower average angle of slope than that adopted by the fragmentary ejecta which now form the

[1] It may be remarked, incidentally, that the dimensions of the ancient crater of Barren Island are about the same as those of the Vesuvian crater of 1822, the formation of which during a paroxysmal eruption was actually witnessed by Scrope.

[2] A short report on the eruption of Krakatau on the 26th, 27th, and 28th of August 1883 by R. D. M. Verbeek, mining engineer; translated from the original Dutch by I. I. Könings; Simla, 1884, p. 4.

[3] A paper on the subject, by my father, Mr. R. Mallet, is to be found in the Quart. Jour. Geological Society, November 1877. The subsidence in question is, of course, of a different kind to that alluded to in the last paragraph with reference to the deficient height of the north-western half of the volcano.

surface of the inner cone. The longest radii from the centre of the crater to the coast (*i.e.*, those to the points where the island has been least encroached upon by subsidence or denudation) measure just 7,000 feet. Taking, then, this as a base-line and 25° as the slope, we should arrive at an altitude of about 3,300 feet. Some deduction must be made from this height on account of the truncation of the cone by the crater, but this is probably more than counterbalanced by the reduction in diameter which the island has undergone through pluvial and marine denudation,—that is to say, the reduction of the base-line from which the vertical line is calculated.[1]

Depth from which the volcano rises.

From what depth of water the volcano rises is not known. Captain Miller found no bottom "close under the rock" at 120 fathoms,[2] while Captain Blair says that "a quarter of a mile from the shore there is no ground with 150 fathoms of line."[3] Dr. Mouat has recorded that "in the immediate neighbourhood of the shore, the water was found to be very deep. Even at the depth of three or four hundred fathoms no bottom could be felt. Captain Campbell himself afterwards gave orders for the renewal of the attempt, and at a considerably greater depth the lead met the resistance of a solid substratum."[4] On the chart of the Bay of Bengal published by the Marine Survey Department (1879) several soundings are given from Barren Island northwards towards Narcondam, and south-westwards

[1] It is unnecessary to take into account the increase in diameter which the island may have undergone as a consequence of the explosive eruption, through the falling of loose material on the lower slopes, as this has long since been washed away again.

[2] Cal. Jour. Nat. Hist., III, p. 422.

[3] Asiatic Researches, IV, p. 398.

[4] Adventures and researches amongst the Andaman Islanders, page 153. It is to be regretted that the exact distance from shore, and the depth of Captain Campbell's soundings were not placed on record. It would appear from the context that he was not sounding for any scientific object, but merely in search of an anchorage, and under such circumstances it appears very extraordinary that the lead should have been lowered to such a depth. One cannot but suspect that there is some mistake, especially as if the depth is so great in the immediate neighbourhood of the shore, the submarine slopes of the island must be far steeper than those above the sea-level. Captain Campbell subsequently obtained soundings of $4\frac{1}{2}$ to 14 fathoms on the south-west side of the island $\frac{1}{4}$ mile from the shore (*l. c.*, page 157, and Selections from Records of the Government of India (Home Department), XXV, page 124). This is the spot where the anchorage is marked on Captain Hobday's map, and where the 'Celerity' rode during our visit.

towards Port Blair. None of these touched bottom at 200 to 680 fathoms; the last-mentioned is 37 miles south-west of the volcano and only 15 from the nearest of the Andaman group. Towards the east the nearest sounding recorded is 100 miles from Barren Island, and that is 1,260 fathoms, with no bottom.

Denudation ridge.

From two to four hundred yards southward and south-eastward of the great crater rim, there is a second, and rudely concentric, ridge, which bears some little resemblance to the edge of a still older and larger crater. But it is clearly due to denudation only, and the water-shed joining the two ridges is almost level. Where rocks having unequal powers of resisting erosion, like lava and scoriæ, occur in alternating masses, the natural tendency, of course, is for pluvial denudation to scoop out the softer into valleys parallel to the outcrop.

Lavas of the ancient cone.

The ancient cone of Barren Island, is, as I have already indicated, largely made up of lava, although perhaps not to such an extent as might appear at first sight. Loosely coherent materials, like agglomerate and scoriæ, are ill-calculated to withstand the wear of the sea, which tends to eat them back until it meets with some more solid rock. Hence one sees comparatively little of the fragmentary ejecta in pulling round the island, although good sections are to be found in a few partially sheltered spots. The lava streams exposed in section along the coast show the usual scoriaceous layer at the bottom of the flow, which is apt to get hollowed out by the waves, until a cave is formed of which the more solid lava forms the roof. Eventually the roof falls in, filling the cave with a confused mass of loose blocks.

Dykes, so numerous in some volcanoes, are not met with very frequently at Barren Island. Close to the landing-place[1] one may be seen, which is vertical, running east and west, or nearly radially to the volcano: it is about 6 or 7 feet thick, and composed of lava very similar to that it penetrates.

[1] At the hot spring.

Specimens of the older lavas (those of the outer cone) were collected from various localities, both in the interior of the crater, where the most ancient flows visible are exposed, and from several points around the coast. Generally speaking, they are more or less vesicular, with small crystals of white translucent felspar, and small granules and crystals of bottle-green translucent augite, disseminated through a dark grey ground-mass. Brownish-yellow olivine is frequently present also. Magnetite is rarely visible to the naked eye, or with a lens, but the specimens, almost without exception, act on the needle, showing that the mineral is present in a finely divided state. Sections of the lava, viewed by polarised light, show the felspar to be triclinic; indeed striæ can sometimes be seen with the help of a lens only. The crystals often contain glass inclosures, and numerous black opaque particles many of which have the section of magnetite crystals. Similar inclosures also occur, although less plentifully, in the augite. Under the microscope the ground-mass is seen to have a micro-crystalline structure, and to be made up of minute crystals of triclinic felspar, with augite, and nearly or quite opaque specks, which appear to consist, at least in part, of more or less decomposed augite, with some magnetite. Molybdate of ammonium indicates the presence of apatite, in some specimens at least. Whilst the lavas are commonly rather finely vesicular, the vesicles at times are more largely developed. Sometimes again the rock is quite compact.[1] In some specimens the porphyritic felspar crystals are thickly strewn; in others they are comparatively few, and the same is true of the augite. The latter mineral is at times partially converted into a dull red opaque substance, through the peroxidation of the iron. Frequently olivine is present also, and in rare cases it replaces the augite almost completely. The ground-mass also varies in the ratio it bears towards the porphyritic portion of the rock, and in the relative proportions of the minerals of which it is composed. When these have been altered, and the iron peroxidised, the ground-mass acquires a dull red tint. An average sample of the lavas yielded 49·55 per

[1] On some compact lava near the landing-place a few green cupreous stains were observed, the copper being, apparently, in the state of silicate.

cent. of silica. Three compact specimens were found to have specific gravities of 2·77, 2·80, and 2·87. Most of those submitted to examination may, I think, be correctly designated 'doleritic lava,' while some verge towards anamesite.

Fragmentary ejecta of the ancient cone.

The fragmentary ejecta which are interstratified with the lavas of the ancient cone are exposed in some few good sections along the coast. At the mouth of the water-course which runs into the sea 300 yards south-west of the most northerly point of the island there is a cliff, some 60 or 80 feet high, composed of ancient scoriæ of a dull red colour. In more than one place on the face of the cliff the irregular stratification of the scoriæ shows unconformity, where layers have been cut away by denudation, and others subsequently deposited with a different inclination. A little further east similar scoriæ are rudely interbedded with irregular layers of lava, some of which are not more than a few inches thick. One hundred yards north-west of the landing-place a somewhat contorted bed of black volcanic ash is interstratified with a similar alternation of scoriæ and lava. Some of the layers of ash resist the weather better than others, and stand out in relief, thus clearly indicating the miniature faults, of a few inches throw, by which the bed has been dislocated. Along the fault-lines, again, the ash has been hardened (probably by infiltration), and the faults are, therefore, marked by lines in relief. Another interesting section is well exposed in the little bay about half a mile south of the landing-place, showing perhaps 50 feet of agglomerate, composed of ash, scoriæ, and ejected blocks of lava up to 3 or 4 feet in diameter. Besides lumps of the ordinary lavas, as described above, there are some of greenish, nearly black, basalt, containing granules of olivine, and breaking with sub-conchoidal fracture—the only true basalt that I have observed on the island. Near the middle of the heterogeneous mass of materials there is a bed of fine, homogeneous ash.

Ancient aqueous (?) deposits.

On the face of the cliff close to the landing-place, a stream of ancient lava overlies a volcanic agglomerate, the great majority of the pebbles and lumps in which are more or less rounded. They are embedded in a sandy, or even clayey, matrix, and in the midst of the agglomerate is a stratum of sandy clay

or fine ash. A similar rock may be seen on the sea-face to the south of the recent lava. It looks very like an aqueous deposit, but air-sorted volcanic materials at times simulate so closely those sorted by water, that the origin of the rock is open to considerable doubt.[1]

Recent ash on ancient cone.

As will be seen from the map, a considerable part of the ancient cone, including both the walls of the crater and the exterior slopes, are covered with ash ejected from the central cone. The greater proportion occurring to the north and north-east may be ascribed, partly to the influence of the south-west monsoon, partly to the crater rim being lower there, and partly to the walls of the crater towards the south-east being too precipitous for much ash to lie on them.[2] The newer ash differs from most of the older in being nearly or quite black, instead of dull red, the iron in it not having as yet undergone much alteration to sesquioxide.

Vegetation on outer slopes of island.

It has been suggested, by more than one writer, that the luxuriant vegetation which clothes the exterior slopes is of quite recent origin,[3] an idea which seems to have sprung, partly from the name 'Barren Island,' and partly from the account left by Captain A. Blair, whose visit in 1789 appears to be the earliest on record. His remark, however, that "those parts of the island that are distant from the volcano, are thinly covered with withered shrubs and blasted trees,"[4] must have referred to the interior of the amphitheatre only. When recently at home on furlough, I found, in the British Museum library, a bound collection[5] of charts, &c., containing, *inter alia*, "a view of the volcano on Barren Island, bearing East, about one mile off, Taken on Board the Honorable

[1] *Vide* p. 15. This deposit may be the same as that noticed in the latter part of the last paragraph.

[2] The limits of the ash within the crater, where the vegetation is scanty and a bird's-eye view of the whole can be obtained from the recent cone, are indicated on the map with some degree of exactness, but those on the exterior slopes are to a large extent conjectural, the vegetation there being so dense that the rocks are very imperfectly seen, both from the crater rim, and from the sea below.

[3] Calcutta Jour. Nat. Hist., Vol. III, p. 423; Selections, Records, Government of India, No. XXV, p. 129.

[4] Asiatic Researches, Vol. IV, p. 398.

[5] King's Library; press mark $\frac{116}{1-51}$ or $\frac{116}{35b}$.

Company's *Snow Viper*, March 23rd, 1789, William Test *Delt.*" Test was evidently the draughtsman to Blair's survey. On this water-color sketch the exterior slopes of the island are represented as being mostly well-wooded, although bare, or grass-covered, in part,[1] in fact not markedly different in any way from what they are at present. There is not a shadow of evidence that any eruption has taken place since then on such a scale as to destroy the vegetation, even if it were possible for the latter to have recovered itself by 1843, when Captain Miller found the outer slopes well wooded.[2]

Valley around the central cone.

As will be seen from Captain Hobday's map, the bottom of the valley, between the walls of the old crater and the newer cone, has an elevation, at the point furthest from the sea, of about 320 feet. From this watershed, the valley, both round the north, and by the south, of the cone, slopes downwards by degrees to the sea. The slope may have been influenced in some degree by an unequal distribution of the ejecta from the central cone, but it is caused in the main, like that of any ordinary valley of erosion, by the pluvial wash of material towards and into the sea. At times, when the latest ejecta in the valley have been scoriæ and ash, the denudation must have been very rapid during heavy rains, but since the pouring forth of the most recent lava streams the erosion has doubtless been greatly diminished. The streams, indeed, by damming up the valleys, and forcing the drainage into a subterranean course, through the scoriaceous layers at the bottom of the lava, have probably stopped *rapid* erosion almost entirely.

Erroneous idea that the sea surrounds the central cone.

It is difficult to understand how the idea that the sea flows round the inner cone, as stated in many standard works on geology, can have originated. The earliest visit of which any record is extant seems to be that in

[1] It is not perfectly clear whether bare rock or grass (dry and yellowish, as it would be in the hot weather), is meant, but I think the latter. Ash would have been given a much darker shade.

[2] Calcutta Jour., Nat. Hist., Vol. III., p. 423.

1789 by Captain Blair,[1] who says that "the base of the cone is the lowest part of the island, and very little higher than the level of the sea," a sentence which is perhaps open to the construction that the sea extended nearly as far as the base of the cone. That this was not his meaning, however, is clear from the original manuscript copy of his "Chart of part of the Coast of the Great Andaman and Adjacent Islands" (1 degree of latitude = $15\frac{7}{8}$ inches), drawn by William Test in 1789, which is contained in the collection of charts in the British Museum Library, to which I have already alluded. Not only does the sea, as represented on this chart, not surround the cone, but it does not approach it more nearly than at present; that is to say, the bay at the landing-place does extend appreciably further eastward than its present limit.

But there may have been a time in the past history of the volcano when the feature, erroneously ascribed to it at the present day, was a reality. After the explosive eruption, by which, probably, the upper part of the mountain was blown away, the bottom of the crater must have been far below the level of the sea, and the western wall either entirely breached, or so weakened as to have subsequently given way to marine and pluvial erosion. An illustration of the appearance which, it may be inferred, the island presented at that time, with the crater filled by, and open to, the sea, is offered in the volcano of St. Paul, in the South Indian Ocean, which,

[1] In the extract from his report, given in Vol. IV of the Asiatic Researches (1795), Captain Blair says he landed on the 24th of March, without mentioning the year. Test's sketch, however, (p. 12) taken off the coast, was made on the 23rd March, 1789. As Test was evidently draughtsman to the survey, there can scarcely be much doubt, I think, that the date of his sketch fixes that of Blair's visit. When recently in England, I examined all the maps and charts of the Indian region, dating before the commencement of the present century, that were available in the libraries of the Royal Geographical Society and the British Museum. With the exception of a map of the "Presqu' Isle de l'Inde au-delà du Gange" par le Sr. Sanson d'Abb, 1652, contained in the collection of charts previously alluded to (p. 12), and on which an island is marked about in the position of Barren Island, but with no name given to it, the earliest map containing Barren Island was one of the Andaman, Nicobar, and adjacent Islands, dated 1778, contained in the "East India Pilot" (British Museum). The names given are "Monday or Barren Island, called also High island." It would seem probable, therefore, that the island was not distinctly recognised, and named, until late in the last century. Possibly there may be some account of it in existence by the first discoverer. (I have been informed by Colonel H. Yule that on a map contained in Linschsten's Voyages, 1598, an island, without name, is marked to the south of "Nacondaon." See foot-note, p. 35.)

however, has suffered more from denudation, on the breached side, than Barren Island, even in its present state. In the course of after-ages the central cone was built up, until, when it appeared above the water, a state of things may be inferred to have originated somewhat resembling that now observable at Santorin. Finally, the cone must have encroached more and more on the surrounding aqueous ring until the latter disappeared altogether and the island assumed its present form.

The central cone is almost identical in size with " the present cone of Vesuvius, which, rising within the great encircling crater-ring of Somma, has a height of about 1,000 feet. But there is undoubted evidence that this cone has been entirely built up during the last 1,800 years, and, what is more, that during this period it has been many times almost wholly destroyed and reconstructed."[1] Monte Nuovo, which was built up to a height of 440 feet in about a week, furnishes an instance of still more rapid growth. It is, therefore, quite conceivable that Barren Island has been seen by some of the early Indian navigators with the central cone surrounded by water, and it may be, even, that some faint tradition to that effect is still extant.[2]

No evidence of recent elevation of the island.

Sir C. Lyell, in the last edition of his 'Principles,' seems to suggest that the non-existence of water round the cone now is due to a modern upheaval of the island, evidenced " by a stratum of rounded stones, like large pebbles, cemented by tufa, " exactly like those of the present beach, but at a considerable elevation " (about 20 feet) above the high-water mark, showing that the sub-marine " base of the island must have been raised since those pebbles had been " washed by the sea," described by Dr. Liebig,[3] whose observations were made in 1858. The Rev. Charles Parish, however, who landed on

[1] 'Volcanoes,' by Prof. Judd, p. 83.

[2] It is *possible* that the cone may have been built up with such rapidity as to have filled up the water ring very soon after the cone first appeared above sea-level, and again there may have been such a long period of quiescence, after the explosive eruption by which the old crater was formed, that the tarn filling the latter was quite filled up, through pluvial wash, before the new cone was commenced.

[3] Selections, Records, Govt. of India (Home Dept.), No. XXV, p. 127; also J. A. S. B., XXIX, p. 1.

the volcano a few years later, says, and I believe quite correctly, that "there are no appearances of any recent elevation of the island."[1] The same opinion was also arrived at by Dr. Playfair.[2] The stratum mentioned by Dr. Liebig does differ markedly from the present beach deposit, in that the latter contains numerous worn fragments of shell and coral, while none such were observable in the former. I think the stratum in question is undoubtedly non-marine, and, considering how closely air-sorted volcano ejecta sometimes simulate those sorted by water, it is questionable whether the stratum is aqueous at all.[3] If any elevation of the island had occurred in recent times, it would almost certainly have left unmistakeable evidences, such as are to be found so abundantly on the shores of Rámri and Cheduba, off the coast of Arakán.[4]

The central cone.

The central cone rises to an elevation of rather more than 1,000 feet above the sea-level[5] or 900 feet from its western foot. Where the sides are composed entirely of scoriæ, ash, and loose ejected blocks, the slope is almost perfectly uniform throughout, at an angle of about 32°. In places, however, where streams of lava have poured down, the inclination is more irregular. On the lower portion of the slope the fragmentary ejecta are loose, but near the top they are cemented together into a friable mass, which, near the edge of the crater, is divided by numerous cracks up to a foot in width. Dr. Liebig states that the cementing material is gypsum: probably it is so in part, gypsum being a common mineral about the crater, but two samples of ash from different spots, that I brought away, were found to contain no sulphate of lime, and appeared to be agglutinated by a siliceous cement.

[1] Proceedings, Roy. Geog. Soc., 1862, p. 216.
[2] Selections, Records, Govt. of India (Home Dept.), No. XXV, p. 123.
[3] *Vide* p. 11.
[4] Records, Geol. Surv. India, Vol. XI, p. 190.
[5] Captain Blair, as quoted by Colebrooke, gives the elevation as nearly 1,800 feet, an evident mistake (probably misprint), as he says that the cone is of the same height as "the other parts of the island," and Test's sketch (*vide* p. 12) represents the elevation, compared to that of the surrounding ring, as not appreciably different to what it is at the present time. See also V. Ball, Records, G. S. I., VI, p. 82.

The cone is almost completely bare of vegetation, the few tufts of grass, &c., which have managed to secure a footing, being mainly on the north side, where the ash is partly protected from the heat of the sun, and consequently not so completely desiccated. On the western slope, especially, the blaze of sunshine in the afternoon raises the black ash to such a temperature that it can scarcely be touched with the hand. It is to the extreme aridity, and shifting character, of the loose materials that the absence of vegetation is due, and only locally, in the neighbourhood of the solfataras, to volcanic emanations. Indeed, there is more vegetation about parts of the crater than elsewhere, some little ferns, &c., growing under the shelter of the rocks, in the moist atmosphere produced by the issuing steam.

The recent crater.

The crater is of an ovoid form (the northern edge of which is, however, straighter than the southern) with the major axis lying about S. by W.—N. by E. The highest points of the edge, to the north and south, are 78 feet above the floor of the crater, while to the east there is a depression, where the edge is only 22 feet above the same level. To the west there is a minor depression, 38 feet above the floor. The materials inside the crater are loose blocks of lava, scoriæ and ash, but to the south-west of the crater-bottom there is a mass of solid lava, which is probably in connection with a flow down the side of the cone which has been covered over by the latest eruption of fragmentary material. The floor of the crater, which is 60 feet in diameter, is a level plain of sand, washed down from the slopes above. If a heavy stone be dropped on it there is a hollow kind of reverberation, which reminds one of the similar phenomenon at the solfatara near Puzzuoli. On the edge of the crater, in the depression to the west, there is an immense ejected block of lava 22 feet long, 11 broad, and varying in height between 13 and 19 feet.[1] It can be plainly seen from the landing-place, forming (as may be noticed in the frontis-

[1] I am indebted for these figures to Dr. J. Reid, who accompanied us during a portion of our expedition. Enormous as this block is, it must be remembered that it was hurled to but a trifling horizontal distance, and probably to a very small vertical height.

piece), a conspicuous object against the sky-line. Dr. Playfair, who landed in 1857, refers to this block, which was also noticed by Mr. Ball in 1873.[1]

Solfataras at the recent crater.

Of several solfataras in, and close to, the crater, the largest is that extending from the northern edge downwards into the interior. It is somewhat in the shape of a triangle with the apex pointing downwards having a base of about 50 feet and perpendicular of some 80. Throughout the greater portion of this area the ground was, at the time of my visit,[2] covered by a crust of sulphur varying from 2 or 3 to 6 or 8 inches in thickness. In one or two spots there was as much as a foot. The sulphur had a columnar structure perpendicular to the surface of the crust, the surface being generally formed by an infinitude of small glittering crystals. The ash beneath (which was dug into to a depth of 6 feet) contained some sulphur disseminated very irregularly through it, and, from its normal black color, was bleached to a greyish-white through the influence of acid vapors. From crevices between some ejected blocks, near the middle of the solfatara, superheated steam, with sulphureous vapor, issued rather copiously, the column, as it rose into the air, being visible from the landing-place, or even some distance out at sea. The temperature of the steam at the point of issue was 219° F., or 9° above the boiling point of water at the elevation of the crater, and the fumes were

[1] Dr. Playfair says that the longest direction of the crater, in 1857, lay N. W.—S. E., and Mr. Ball, writing in 1873, makes a similar statement. Lieutenant Heathcote, again, who accompanied Dr. Playfair (*vide* Mouat's Researches amongst the Andaman Islanders, p. 53) calculated the height of the cone, trigonometrically, at 975 feet above the sea (Selec., Rec. Govt. of India, XXV, p. 128), or 40 feet lower than Captain Hobday's value, from which it might be inferred that the cone has gained 40 feet since 1857. But the descriptions of the crater by Dr. Playfair, Dr. Leibig, and Mr. Ball, especially by the last-named, agree so well with its present appearance, that it is extremely difficult to believe that an eruption has occurred since their time, by which the direction of the major axis has been shifted some 60°. It is plain, also, from Dr. Playfair's view of the island, and the copy of a photograph given at p. 9 of the same volume, that the western depression, and the great ejected block, were in the same position as at present. The position of the block seems to furnish almost incontestable proof that the altitude of the cone is the same now as in 1857.

[2] I say "was" because the richest part of the sulphur was collected and removed by the party of convicts placed at my disposal.

found to redden litmus paper immediately, while they had no action on acetate of lead paper. The surfaces of the rock near the vents were covered with a white vesicular stalactitic substance, and with a red and orange deliquescent matter. The former was found to consist mainly of a basic sulphate of alumina, with a little calcium chloride, while the red incrustation consisted of calcium chloride, with basic sulphate of alumina and ferric oxide.[1] Fibrous gypsum also occurs along with the other products of alteration.

There is another smaller solfatara to the north-east of the above extending from the edge of the crater down the outward slope, with an area of about 30 feet × 20. There was a similar crust of sulphur, with bleached ash beneath: in this, at a depth of 7 feet, a mass of pasty white matter was come upon (like the ash around it, so hot that it could not be touched), specimens of which dried into a mealy substance like kaolin, but which were found to consist of a basic sulphate of alumina with a little potash and lime. To the south of the crater bottom there is a third solfatara, from which steam issues here and there; and in some other spots about the crater sulphur occurs in a similar way, but in smaller quantity.

Lavas of the central cone.

The oldest visible lava in connection with the central cone is probably that which forms a slight hummock on the north-western slope, some 250 feet below the crater. The stream which doubtless flowed down from this point has disappeared, partly through the lava having disintegrated, and rolled to the bottom of the cone, and in part probably through its having been covered over by scoriæ, &c. The lava inside the crater has already been mentioned. Of what may be called quite recent lava there are three distinct flows, which may be distinguished as the eastern, the southern, and the northern

[1] The occurrence of native calcium chloride is of some interest, as it is a mineral which has not been often found hitherto. It has, however, been observed at some of the fumaroles of Hekla, and was noticed amongst the sublimates produced during the Vesuvian eruption of 1872, by Palmieri. It has been given the mineralogical name of *chlorocalcite*. There is a specimen, from Vesuvius, in the Museum at Bonn, consisting of small white isometric crystals hermetically sealed in a glass tube.

streams. In general appearance they are all very similar to each other, presenting the same exceedingly rough, hummocky, and fissured surface, with the black, scoriaceous crust broken into pieces of every size up to those many tons in weight. Great hollows are seen in places, where, the lava having flowed away from underneath, the crust has given way and fallen in. The streams have the lateral and terminal 'banks'[1] so frequently noticed in the descriptions of other volcanoes. The lava is almost perfectly bare of vegetation, even a stray blade of grass being rarely seen upon it.

The macroscopic and microscopic examination of the recent lavas does not indicate any essential difference between them and those from the ancient cone. There is the same association of white, translucent, triclinic felspar crystals, and bottle-green translucent augite, with frequently a little olivine, in a micro-crystalline ground-mass composed of triclinic felspar, augite, magnetite, opacite, apatite, &c. An average sample was found to contain 50·10 per-cent. of silica.

The age of the eastern flow, with reference to the others, cannot be determined with certainty, as it does not come in contact with either.

The southern stream broke out a little more than half way up the cone, at a point now marked by slight projection. After pouring down the side of the cone, it followed the course of the valley into the sea, which has, since then, cut the face into a cliff 10 or 15 feet in height. This was the largest flow of all, a considerable part of the area covered by it being obscured by the sand, which has been washed down from the old crater walls to the south. There seems to have been a subsequent minor gush from the same orifice, which scarcely reached beyond the base of the cone.

The northern stream broke forth about 250 feet below the crater; close to the point of issue there is a solfatara, at one part of which, about 25 feet in diameter, was the richest crust of sulphur met with anywhere, averaging perhaps 4 inches in thickness. Beneath was bleached ash, and, on digging through this, in the centre of the crust, to a depth of 7 feet, an open hole 8 or 9 inches in diameter was disclosed, into

[1] *Vide* sections (drawn on a horizontal and vertical scale of 4 inches to the mile) at end of report.

which a stick could be thrust for 8 feet. From the mouth steam issued rather copiously at a temperature of 170° : it had no action on either litmus or lead paper. In crevices of the lava were well-formed aggregated crystals of sulphur, in unmodified rhombic octahedrons (P.) From the point of issue the molten rock, after reaching the base of the cone, flowed down the valley, and over the previous stream from the south, the termination of the later current being marked by a bank a little to the west of the foot of the cone.[1] There is no essential difference between the superficial part of the lava on the side of the cone and that in the valley below; both are about equally vesicular.

There are several reasons for believing that the lava has been emitted within quite a recent period, almost certainly within the last century. The absence of vegetation, in a climate where foliage grows so luxuriantly where once it has established itself, as on the lavas of the outer cone, may be taken as one indication; while the rapid cooling of the hot spring, which, as I shall endeavour to show further on, owes its existence to the percolation of the drainage from the amphitheatre through the still heated porous materials beneath the lava, is another and still more important one. Again, Captain Blair makes no mention of the lava, an object so prominent that it could not possibly escape his attention, but he says, "The volcano was in a violent state of eruption, bursting out im- "mense volumes of smoke, and frequently showers of red-hot stones. "Some were of a size to weigh three or four tons, and had been thrown "some hundred yards past the foot of the cone. There were two or three "eruptions while we were close to it; several of the red-hot stones rolled "down the sides of the cone, and bounded a considerable way beyond us." If the stones were accompanied by finer fragmentary material, such ought to be now found on the lava, if it were then in existence, but it is

[1] Dr. Playfair's plan of the island, as seen in 1857, appears to represent only one stream of lava, flowing from the northern part of the valley into the sea. Supposing this to be an accurate drawing, Dr. Playfair's stream must have been buried beneath the southern and northern flows, as represented on Captain Hobday's map. Dr. Liebig, however, whose visit was only three months later than Dr. Playfair's, says that "*surrounding* the base of the cone, the bottom of the valley is filled with black masses of *cold* lava." (the italics are mine). If the lava had been less than three months old it would have been still red hot, at the sides of the fissures, and probably evolving too much steam to escape notice (*vide* foot-note, p. 25). The accuracy of Dr. Playfair's plan must, I think, be looked upon with very great doubt.

free from such except in places where ash has *rolled* down from above, or been washed on to it by water.[1] The earliest account in which mention is made of the lava (rather obscurely) is that by the commander of a ship who landed in March 1832.[2] But, judging from the quantity of sand that has been washed down from the walls of the ancient crater to the south, and covered a considerable part of the southern lava stream, I should be inclined to assign the greatest possible age to this flow at least. It is well known that the ejection of fragmentary material is often the first stage of an eruption, and followed by the emission of lava, and it seems very probable that the southern stream broke out immediately after the eruption witnessed by Blair. The northern stream may have poured forth very shortly after, but there is no positive proof of its existence much before 1858, when it was seen by Dr. Liebig.[3]

Condition of activity of the volcano during the last century.

Mr. Ball has given, in a tabular form, an abstract of the accounts left by previous observers,[4] a slightly altered edition of which, in as far as it relates to the state of activity of the volcano, is appended herewith.

Date.	State of activity.	Authority.
12th May, 1787 .	"Column of smoke, ascending from the summit," was seen from a distance of 7 leagues. No nearer approach to the island was made.	Lieutenant R. H. Colebrooke; Asiatic Researches, Vol. IV, p. 397.
24th March, 1789	"The volcano was in a violent state of eruption, bursting out immense volumes of smoke, and frequently showers of red-hot stones. Some were of a size to weigh three or four tons, and had been thrown some hundred yards past the foot of the cone. There were two or three eruptions, while we were close to it; several of the red-hot stones rolled down the sides of the cone, and bounded a considerable way beyond us.	Captain Blair, quoted by Colebrooke, *l. c.* Captain Blair's first report on the Andamans, which contains his description of Barren Island, does not seem to have been published. The second is included in Selec. Rec., Govt. of India (Home Dept.), No. XXIV.

[1] The loose *blocks* and *lumps* of scoriaceous lava, found on the surface of the flows, are, I believe, almost entirely due to the breaking-up of the crust during its solidification, while the streams were still in motion.

[2] J. A. S. B., Vol. I, p. 128.

[3] Captain Miller mentions the lava *streams* that he saw in 1843, but does not describe them in detail.

[4] Records, G. S. I., Vol. VI, p. 84.

Date.	State of activity.	Authority.
	Part, at least, of the recent lava, was probably emitted soon after Captain Blair's visit.	*Vide* p. 21.
1791 . .	A quantity of very white smoke close to the crater.	Horsburgh's India Directory, 5th ed., Vol. II, 1843, p. 55.
1803 . .	Exploded regularly every 10 minutes, projecting each time a column of black smoke perpendicularly to a great height. In the night a fire of considerable size continued to burn on the east side of the crater.	Horsburgh.
March, 1832 .	"Large volumes of thin white smoke kept continually issuing" from the summit.	Commander of a ship; J. A. S. B., Vol. I, p. 129.
April, 1843 .	From the summit of the cone "a clear and full stream of transparent vapor issued, so transparent that it was not perceptible from the sea."	Captain Miller; Calcutta Jour. of Nat. Hist., Vol. III, p. 423.
1852 . .	Very active.	Bombay Times, July 1852.
18th Dec., 1857 .	"Some smoke was seen occasionally to issue from the slope of the cone" a little way below the ejected block mentioned at p. 17.	Dr. Playfair; Selec. Rec. Govt. of India (Home Dept.), No. XXV, p. 123.
19th March, 1858	"Clouds of hot watery vapor," with a sulphurous smell, issued from cracks near the summit, on the northern and southern edges of the crater.	Dr. Liebig; Zeitschrift der Deuts. Geol. Gesellschaft, Vol. X, p. 299. Selec. Rec., Govt. of India, No. XXV, p. 126; also in J. A. S B., Vol. XXIX, p. 1, and in Mouat's Researches amongst the Andaman Islanders.
1862 . .	Sulphureous vapors issuing along the edge of the crater.	Rev. C. Parish; Proceedings, Royal Geog. Soc., Vol. VI, p. 217.
19th April, 1866.	A whitish vapor was evolved from several deep fissures near the summit.	Andaman Committee; Proceedings, A. S. B., Oct. 1866, p. 215.
March, 1873 .	From the highest point on the northern edge of the crater a thin column of white vapor, and sulphureous fumes, were slowly poured forth.	Prof. V. Ball; Records, G. S. I., Vol VI, p. 88.
February, 1884 .	Superheated steam, with sulphureous vapor, issued rather copiously from the solfatara on the north side of the crater, the column, as it rose into the air, being visible from the landing-place, or even some distance out at sea. Steam in smaller quantity issued from some other spots also.	p. 18.

Recent aqueous deposits.

In the lower part of the main gorge, which debouches to the south of the alluvial plain, there is an agglomerate, composed of rounded and angular lumps of volcanic rock in a finer matrix, which appears to be a deposit of the stream itself. The water has subsequently cut through, and exposed the rock in section.[1] At the debouchure there is a fan-shaped mass of detrital matter, which merges into the alluvial plain to the north. The latter, which, as will be seen from the map, is far from level, being 250 feet above the sea at one end, and only 80 at the other, is formed cf volcanic sand, most of which has been washed out of the above gorge, the rest having come from minor water-courses to the east. The sand is covered with coarse grass, and occasional bushes. As previously explained,[2] the deposit, in as far as it overlies the lava, seems to have been formed within the last century. After heavy bursts of tropical rain the amount of detritus swept down the gorges is probably very large in proportion to their size, while the frequency with which the lava crops through, shows that the sand is not very thick.

At the debouchure of the gorge to the north of the anchorage another aqueous deposit may be seen, and doubtless there are many others on the island.

The sand on the beach near the anchorage is somewhat remarkable, being composed almost entirely of bottle-green translucent augite, and brownish-yellow olivine, with some grains of coral and broken shell, &c.

Hot spring.

Taking into account the heavy tropical rains at Barren Island, one would expect, *a priori*, a certain amount of drainage-water from the amphitheatre, which has an area of rather more than a square mile, and the natural outlet for such drainage would be the breach, towards which, as previously said, the valley between the old crater walls and the newer cone, has a tolerably steady slope.[3] But, owing to the porous nature of most of the volcanic products, the drainage in the cold weather, and probably at all times, except after

[1] It is scarcely necessary to say that this, and all the other, stream-beds in the island, are perfectly dry in the cold weather, and probably at all times, except after heavy rain.

[2] p. 22.

[3] p. 13.

heavy falls of rain, is carried on entirely beneath the surface, by percolation through the ash, &c., until it reaches the level of the sea, where it is, I think, unquestionably to be found in the springs of hot water which gush forth on the beach at the landing-place. The shore, between the cliffs of ancient lava and the recent stream, has a length of about 40 yards, and along it the hot water issues in numerous places from between the shingle. The level of the springs rises and falls with the tide, as was distinctly shown by a well, sunk in the ash, about 20 yards from the beach, the bottom of which filled with hot water at the flow of the tide, and ran dry at the ebb. The high temperature of the water is, I think, beyond doubt, due to the recent lava, and consequently the scoriaceous and other porous material beneath it, through which the drainage percolates, not having yet completely cooled.[1] The accounts given by different visitors show conclusively that the spring is rapidly falling in temperature, a result naturally to be expected from the cooling of the lava.

Date.	Temperature of springs.	Authority.
March, 1789	No mention of the spring	Captain Blair.
March, 1832	"On approaching to within a hundred yards of the shore, we were suddenly assailed by hot puffs of wind, and on dipping our fingers into the water, were surprised to find it as hot almost as if it had been boiling. The stones on shore, and the rocks exposed by the ebbing of the tide, were smoking and hissing, and the water was bubbling all round them."	Commander of a ship.
December, 1857	Temperature "too high to be borne by the hand, the mercury in the only thermometer in our possession rising immediately to 140°—its limit."	Dr. Playfair.
Ditto	"A natural boiling spring"	Dr. Mouat.
March, 1858	"The water, where escaping from the rock, must have been nearly at the boiling point."	Dr. Liebig.
1862	"Scalding hot"	Rev. C. Parish.
April, 1866	158° to 163° F.	Andaman Committee.
March, 1873	130° F.	Prof. V. Ball.
February, 1884	106° to 116° F.	F. R. Mallet.

[1] The extreme slowness with which some lava streams cool is well known; thus Dr. Geikie cites an instance, in Mexico, where a cigar could be lighted in the fissures 21 years after the outpour of molten rock, which was still steaming after 87 years had elapsed. (Text-Book of Geology, p. 230.)

Captain Blair's silence respecting the hot spring quite tallies with the supposition that the lava, which he does not mention either, was emitted after his visit.[1] The earliest allusion to the spring is that by the observer who saw it in 1832, when the amount of heat given off (by the spring itself, and by the sea in the immediate neighbourhood) seems to have been much greater than that noticed by later visitors. The lava up to about the year 1860, although continually cooling, appears to have still retained sufficient heat, at the base of the flow, to maintain the spring at, or near, the boiling point, but during the last quarter of a century the further cooling of the rock has resulted in the spring gradually sinking to 116°.

Corroborative evidence, as to the source whence the water derives its heat, may be found in the observation that the temperature of the different springs increases with their proximity to the recent lava. Thus a thermometer immersed in the most northern of the little pools, where the water was welling out, rose to 106°; in the next, and succeeding ones, to 107½°, 109°, 109½°, 112½°, 114½°, and in the spring nearest to the lava to 116°. The water does not redden litmus paper, and no smell of sulphuretted hydrogen was remarked at the spring itself, but when bottles of the water were opened some weeks afterwards the odour was very perceptible, and lead test paper introduced into the neck was soon blackened. The total solid matter was found to be—

		Grammes per litre.	Grains per gallon.
Hot spring on beach	water taken at low tide .	3·32	232·3
	„ „ „ nearly high tide	3·04	213·1
Well about 20 yards inland; water taken at nearly high tide		3·14	219·6

The main saline constituents are sodium and magnesium as chloride and sulphate, with calcium and magnesium carbonate, the carbonates amounting to about one-fifth of the total. A portion of the salts is doubtless derived from the action of the hot water on the rocks it passes through, the remainder being due to mixture with sea-water. The reason why the spring is slightly less saline at high

[1] p 21.

than at low tide appears to be this: the water of the sea soaks for an unknown distance inland, through the porous volcanic material, the level of this inland subterranean water rising and falling with the tide. There is, in fact, an inland tide, decreasing in amount (on account of the drag caused by the resistance offered by the ash, &c, to the free passage of water) to some line where it becomes zero, and the salt water remains at a constant level. The drainage of the amphitheatre, then, soaks downwards until it reaches the inland salt water, over which, on account of the difference in specific gravity, it flows onward to the sea. At high tide, therefore, the drainage reaches the sea through ash which is never wetted by salt water, while at low tide it percolates through, and washes, material from which the salt water has just retired.

As the hot spring is the only known source of water on the island, its potable character is of importance with reference to the sulphur question. When sipped in small quantity, fresh from the spring, the water seems to be fairly good,[1] the heat apparently disguising its taste, but, after cooling, it is manifestly brackish, and most unpalatable, so much so that, during our stay on the island, water from the steamer was exclusively used for drinking and cooking. While water containing 70 grains of saline matter per gallon is considered bad, that of the hot spring contains over 200, and even if the carbonates were precipitated by boiling the quality would not be very greatly improved.

Better water probably obtainable from wells.

Were there a sufficient object in procuring a supply of better water, it could probably be obtained by sinking inland. A well, for instance, at the western foot of the newer cone, would probably yield water less brackish than that of the hot spring, and would be in a closely analogous position to some of the wells in the cantonment at Aden which yield drinkable liquid.[2] The ground might, however, be found too hot to dig through, and better water, at a lower temperature, might be expected at the debouchure of the water-course south of the alluvial plain. But water could not be depended on

[1] It has been reported of good quality by more than one visitor to the island.
[2] Vol. VII, p. 265.

with certainty much above sea-level, or at a depth, at the point in question of some 200 feet.

Economic resources; Sulphur.

The solfataras have been already described (p. 18, 20), but it remains to discuss their value as a source of sulphur. We have, firstly, the superficial crusts, containing a high percentage of the mineral; and, secondly, the ash beneath, through which sulphur is more or less disseminated. The aggregate area of the solfataras at the crater and at the point of eruption of the northern stream of lava, does not, I think, exceed some 5,000 square feet. The crusts, although, in some places, several inches thick, were absent in others, so that the average thickness was probably not more than 2 or 3. Taking the specific gravity of the loosely coherent sulphur at 1·5, the above figures would give a total of not more than a few dozen tons, from which some deduction would have to be made for impurity. This estimate, although crude in the extreme, and without any pretensions to accuracy, at least suffices, I think, to show that only a very limited quantity of sulphur is to be obtained. During our stay at the island the party of convicts collected 97 bags-full, weighing 6,840 lbs., or rather more than 3 tons. This was the *crème de la crème* of the deposit (the last 10 or 20 bags, even, containing rather more impurity than the remainder). A sample brought to Calcutta yielded on assay—

Sulphur	88·92
Water	2·44
Fixed residue	8·64
	100·00

The ash beneath the crusts was dug into to a depth of several feet, and samples taken for assay, which gave—

	Sulphur. p. c.
Largest solfatara in crater; ash 2½ feet from surface (stones excluded=, say, ½ of the total)	1·06
Do. ; ash 6 feet from surface (stones excluded=, say, ½ of the total)	12·98
Solfatara on northern outer slope; ash 4 feet from surface	·80
Do. do. ; „ 7 „ „ „	·15
Solfatara at point of issue of recent lava; ash 1½ feet from surface	·04
Do. do. ; ash 7 „ „ „	·02

It will be seen that, with one exception, the proportion of sulphur is quite trifling, and decreases with increased depth. Considering that the rich sulphur occurs in superficial crusts, apparently indicating that it is only freely deposited where there is unrestricted access to the atmosphere,[1] a diminution in the proportion contained in the ash might be expected as the depth increases. The exceptional case is, therefore, probably due to some local and special cause, and the figures given are sufficient to show that a large proportion, at least, of the ash contains too low a percentage of sulphur to be worth treatment. Including the stones, which contain scarcely any sulphur, even the ash second on the list would not yield more than 7 or 8 per cent.

I have previously stated[2] that there appears to have been no eruption from the crater since 1857-58, when it was examined by Playfair and Liebig, who described the deposits of sulphur in their time. As, beyond the taking of mere hand specimens, these were never disturbed until our visit, it is clear that the crusts of a few inches in thickness, described above, have taken *at least* a quarter of a century to form, from which it may be inferred that, if the sulphur were worked out now, a fresh crop could not be expected until after many years, unless the volcano should become more active than it has been during the last few decades.

That, besides the deposits of sulphur now visible, there are other, and older ones, which have been buried beneath the later showers of ash, is very likely. But any search for such by digging must be purely haphazard, and, unless perhaps in the immediate neighbourhood of the crater, the chance of success would be very small.

It is, then, I think, clear that the sulphur is not sufficiently abundant to allow of its being profitably worked by convict labour, with the attendant expenses for police and communications, &c.[3] But if taken up in a small way by a native contractor or lessee, who was acquainted

[1] Volcanic sulphur is generally considered due, either to the reaction of sulphurous anhydride and sulphuretted hydrogen on each other, or to the decomposition of the latter by the oxygen of the air.

[2] Foot-note, p. 18.

[3] A similar opinion was arrived at by Mr. Ball (Records, G. S. I., Vol. VI, p. 88).

with some simple method of purification,[1] he might be able to work out the deposits at a profit. Firewood for distilling the sulphur is abundant. But, on the other hand, the present want of good water on the island is a difficulty which must be overcome as a *sine quâ non* to any lengthened stay there.

Volcanic ash as an ingredient of hydraulic mortar.

There is an unlimited supply of fine volcanic ash, or 'puzzuolana,' on the island, a material which is very largely used in Central France, and other parts of Europe, as an ingredient of hydraulic mortar or cement. It is obtainable in abundance close to the landing-place, and, if it could be shipped to Port Blair at a sufficiently low rate, would be worth experimenting on, in combination with the lime which is there procurable.[2]

Desiderata.

In conclusion, I may perhaps suggest to future visitors that soundings near the island would possess considerable interest, as at present we have no certain knowledge as to the depth of water from which the volcano rises. The temperature of the hot spring should be noted, and observations made on the thickness of the *fresh and undisturbed* sulphur crusts. What was left after our visit was so completely trampled down by the working party, that no difficulty ought to be experienced in distinguishing the new crusts formed since February 1884. From their thickness an estimate can be formed of the rate at which the sulphur is deposited. The recent lava streams have been accurately delineated by Captain Hobday, but the remaining geological lines on his map are open to revision in detail. As Captain Hobday and I were working simultaneously, his map, of course, was not available for geological purposes at the time. The lines in question, therefore, were added subsequently from my notes, made on a rough sketch, kindly supplied me by Captain Hobday from his plane-table.

For the ascent of the cone the best route from the landing-place will be found along the northern edge of the northern lava stream, and then up the course of the lava itself to the point where it first broke out. From that point no difficulty will be experienced in reaching the summit.

[1] Like that, for instance, practised in the Sulimán Hills, where one ordinary earthen *ghara* is used as a retort and another as a receiver (V. Ball, Records, G. S. I., Vol. VII, p. 158).

[2] Records, G. S. I., Vol. XVII, p. 85.

NARCONDAM.

Narcondam lies about 75 miles north-north-east of Barren Island.

General appearance.

Like the latter, it rises abruptly out of deep water, the only recorded sounding off the coast that touched bottom being one of 450 fathoms two miles from the south-eastern shore.[1] To speak of the mountain as a cone conveys a rather false impression, but it has a roughly conical form, with sides deeply scored by ravines. The summit, 2,330 feet above the sea, is rather to the south of the centre of the island, the northern part of which is occupied by hills of comparatively small altitude. Except along the coast-line, where, especially in the southern half of the island, the rocks have been eaten back into cliffs, which sometimes tower above the sea to a height of several hundred feet, the island is covered with dense jungle. Most of it is luxuriant forest, but in places, as near the top of the mountain, it is of a more scrubby character.

No crater.

There is no crater at the summit. The culminating portion of the volcano includes three hummocks, of which the northern is the highest, or 175 and 135 feet above the minor summits to the south and south-east. It may be that these elevations are the last remnants of a once-existent crater, of which all else has vanished through the assaults of time; but the question is open to argument, and will be alluded to again further on. Mr. Ball has rightly pointed out that what Dr. McClelland (judging from a sketch of the island only) took for "lava currents descending from the crater to the base" are merely the deep ravines already alluded to.

Volcano extinct.

Neither at the summit, nor in any other part of the island, was the faintest sign of recent volcanic activity observed.

Character of lavas.

Specimens of the lavas were collected from the highest point of the mountain, and from different localities on the ascent, and around the coast. They are all compact or very slightly vesicular lava, in which crystals of white trans-

[1] Bay of Bengal Pilot, p. 256.

lucent felspar, and black or dark-brown hornblende are disseminated through a ground-mass, which is (generally light) grey in unaltered specimens, but pale red in those which have undergone weathering, and in which the iron has been peroxidised. The felspar crystals vary from a quarter of an inch in length downwards, averaging perhaps one-eighth or so, and are shown by the polariscope to be triclinic, as a general rule, although orthoclinic felspar is sometimes present in a subordinate degree. Numberless inclosures are contained in the felspar, glass inclosures, often containing bubbles, being amongst the most abundant. The crystals of hornblende are about as large as those of felspar, but are far less numerous. They sometimes stand out prominently on weathered surfaces of the rock, owing to their resisting disintegration better than the ground-mass, and can then be detached for examination. The combination $\infty P.\ \infty \not{P} \infty.\ P.\ 0 P.$ occurs both in untwinned crystals and in hemitropes, while $\infty P.\ \infty \underset{\cdot}{\not{P}} \infty.\ P.$ was observed in hemitropes only. In thin sections the mineral is dark brown and strongly dichroic ; when decomposed it is nearly or quite opaque.

Besides the above prominently developed minerals, augite is sometimes present in a subordinate degree, the mineral having in thin sections a pale green, or, when decomposed, reddish or brown colour. An occasional hexagonal scale of rubellan, or crystal of magnetite,[1] may sometimes be seen with the lens, and minute crystals of apatite are included in some instances. The ground-mass of the rock is micro-crystalline, and mainly felspathic (the felspar being similar to that of the larger crystals), with specks of hornblende, magnetite, opacite, &c. An average sample of the lavas yielded 58·55 per cent. of silica. Three specimens (which, however, were not perfectly free from minute cavities) were found to have specific gravities of 2·53, 2·53, and 2·58.

The lavas of Narcondam are essentially hornblende andesites, and are of a decidedly more acid character than those of Barren Island, which is shown by the greater predominance of felspar, and the paler color of

[1] Thin layers of magnetic iron-sand occur, here and there, on the beach, together with sand composed of comminuted lava, coral, &c. Many of the grains are octahedral and dodecahedral crystals.

the rock induced thereby, the lower specific gravity, and the substitution of hornblende for augite.

Agglomerates.

Volcanic agglomerates, composed of rounded and angular fragments of lava of every size, up to 3 or 4 feet in diameter, embedded in a finer matrix, are largely exposed in section along several parts of the coast. Rounded nodules of rock, often darker-colored and finer-grained than the surrounding matrix, and standing out prominently on weathered surfaces, owing to their yielding less than the matrix to atmospheric attack, also occur frequently in rocks which have every appearance of being true lava. It is a matter of great difficulty, in some cases, to distinguish between the lavas and the agglomerates, owing to the quasi-agglomeratic character of rocks which apparently should be classed with the former, and the consolidation of the latter.

Type of volcano.

Taking into account the comparatively acid character of the Narcondam lavas, and the absence of any recognisable crater, the question arises whether the volcano may not be of the 'endogenous' type, and produced by the extrusion of viscid lava without the accompaniment of crater-forming materials. This view certainly derives some support from the general uniformity in character of the lavas, and the absence of clearly marked alternations of lava and ash like those seen at Barren Island. Viewing the question in this light, the agglomerates must be regarded as of aqueous origin, having been formed by the pluvial wash of material down the flanks of the mountain. That they are not marine is indicated by the absence of coral, &c., like that found so abundantly in rolled lumps on the present beach.

There are cases, indeed, one of which is to be found in the small island near the anchorage, where lava seems to overlie agglomerate, as if it had been poured forth in a separate flow. But the difficulty, already alluded to, of distinguishing, beyond the possibility of doubt, between some of the lavas and tuffs, render these cases not so clear as would be desirable.[1]

[1] In the case just mentioned, microscopic sections of the overlying and underlying rocks do not show any essential difference.

However the absence of any crater, now, should be accounted for, there is no lack of evidence pointing to the immense period during which the volcano has been extinct. If the crater has been destroyed by denudation, we have the evidence in such destruction, while, if the volcano be of the endogenous type, similar testimony is offered by the profound gorges which have been scooped out of the mountain flanks by pluvial action,[1] and the encroachments of the sea, shown by the lofty cliffs and outlying rocks.

Volcano long extinct.

The derivation of the word 'Narcondam' has been discussed by Colonel H. Yule, in his translation of Marco Polo's Travels. "Abraham Roger tells us that the Coromandel "Brahmans used to say that the *Rákshasas* or Demons had their abode on "the Island of Andaman lying on the route from Pulicat to Pegu," and "also that they were man-eaters. This would be very curious if it were "a genuine old Brahmanical *Saga;* but I fear it may have been gathered "from the Arab seamen. Still it is remarkable that a strange, weird-look-"ing island, a steep and regular volcanic cone, which rises to a height of "2,150 feet,[2] straight out of the deep sea to the eastward of the Andaman "group, bears the name of *Narcondam,* in which one cannot but recognise "नरक, *Narak,* 'Hell'; perhaps *Naraka-Kuṇḍam,* 'a pit of hell.' Can "it be that in old times, but still contemporary with Hindu navigation, "this volcano was active, and that some Brahman St. Brandon recog-"nised in it the mouth of Hell, congenial to the Rákshasas of the adja-"cent group?"[3]

Derivation of the word 'Narcondam.'

It will have been seen, from the foregoing description, that the term "pit of hell" is quite inapplicable to the island now known as Narcondam—a lofty conical mountain, without any crater or depression at the top, and which, it may be confidently asserted, has never shown any sign

[1] No perennial source of fresh water has been discovered on the island, but a supply might probably be obtained by sinking a well, down to the sea-level, in the bed of one of the larger water-courses.

[2] This was the height given by Captain Blair.—F. R. M.

[3] The book of Ser Marco Polo, translated by Colonel Henry Yule, C.B., 2nd edit., Vol. II, p. 294.

of activity during the historic epoch. On the other hand, the name would apply most aptly to Barren Island, with its deep, pit-like amphitheatre, from the centre of which sulphureous fumes continually arise, and whence showers of red-hot stones, and streams of molten rock, have been vomited forth within the last century. At a comparatively recent date the central cone may have been much lower than at present,[1] giving the volcano a still more pit-like aspect than it now wears.

The question then suggests itself whether there has not been some confusion in the application of the name 'Narcondam'; whether it was not applied by the early Hindu navigators to the volcano now known as Barren Island, and subsequently misapplied to the northern island: In the hope of throwing some light on this point I recently searched all the available old maps of the region in question, at the British Museum and Geographical Society's libraries, but no decisive result was obtained.[2]

[1] p. 15.

[2] On a map of the East Indian Islands by Ferando Berteli, 1565, the "Andemaom" Islands are marked, but neither of the islands in question.

On a map in Linschsten's voyages (1598) "Nacondaon," as I am informed by Colonel Yule, is marked, with another nameless island to the south of it.

On a map of the "Presqu, Isle de l'Inde au-delà du Gange, 1652 (see p. 14), "Nacandaon" is placed about half way between the "Andemaon" and Cocos Islands (rather nearer the former). An island is marked in about the position of Barren Island, but no name is given to it.

On a map entitled "Royaume de Siam avec les Royaumes qui luy sont Tributaires, et les Isles de Sumatra, Andemaon, etc. Selon les observations des Six Pères Jésuites," (&c., &c.) "Par le Père Coronelli, Cosmographe de la République de Venise," 1687, "Marcondao" is marked in approximately the position of the present Narcondam. No island is marked in the position of Barren Island.

Various other atlases of later date have Narcondam more or less nearly in the position of the present island of that name, and no island corresponding to Barren Island.

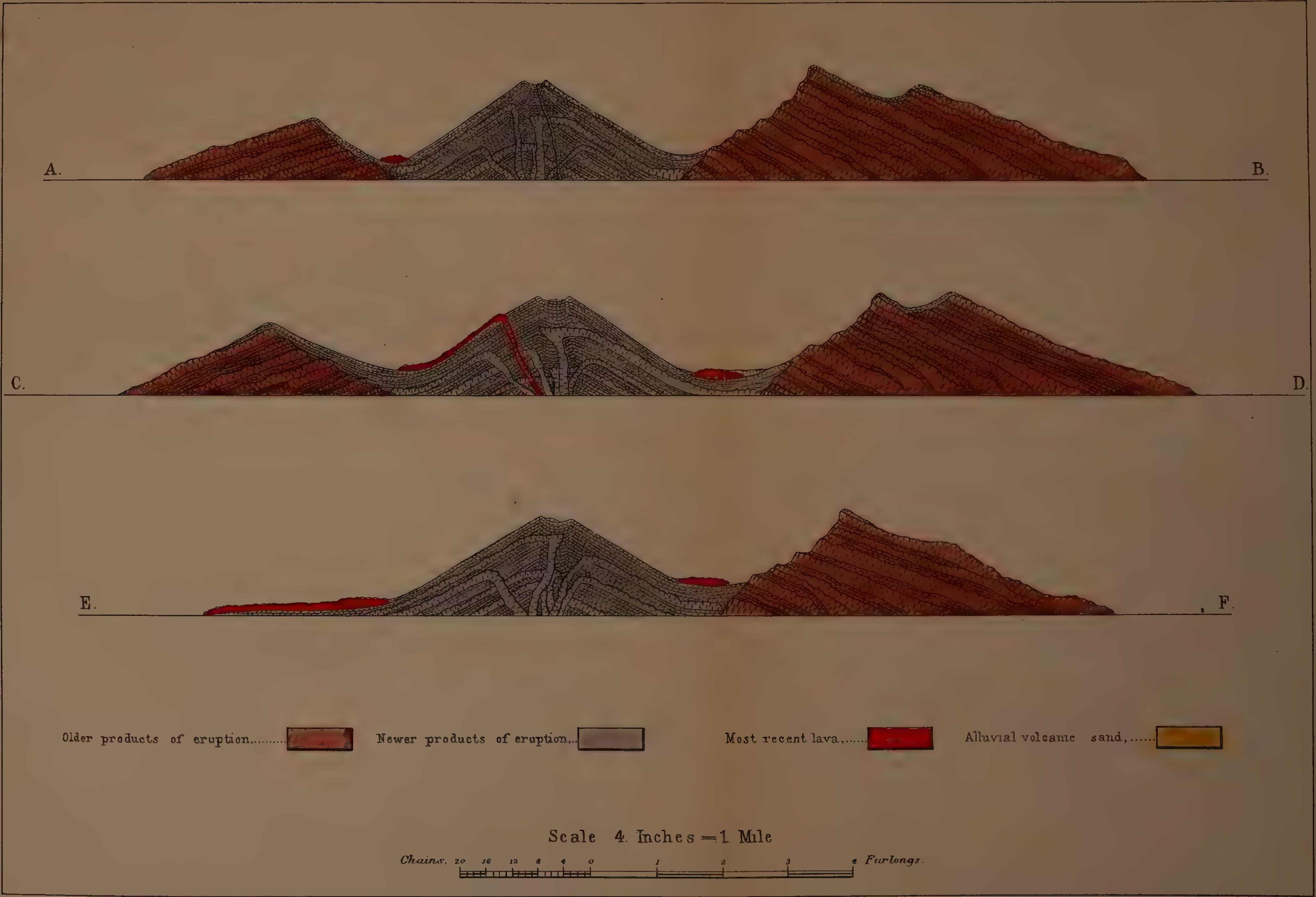
The "East India Pilot" or "Oriental Navigator" (Geog. Soc. library) contains two maps referring to the area in question. On a "General Map of the East Indies" (printed January 1781) "Narcondam according to the Portuguese" is placed in 13° 45′ N. lat. and 110° 35′ E. long. (from Ferro), and "Narcondam or High Island according to the French" in 12° 50′ and 110° 55′. On a "Chart of the Bay of Bengal" (April 1778) "Narcondam of the Portuguese" is placed in 13° 47′ N. lat. (no lines of longitude) and "High I. or Narcondam of the French" in 13° 20′. "Flat I." (N.) in 12° 3′ and "Flat I." (S.) in 11° 22.′ Between these two islands the words "the Barren Is." are print d. On both maps there is a small islet marked on the north side of the French Narcondam, or in a similar position to the islet near the anchorage at the present Narcondam.

On a chart (1778) in the "East India Pilot" (British Museum), the name "High Island" is applied to Barren Island (see foot-note, p. 14), so that there certainly has been confusion of some sort, with reference to the names of the two volcanoes.

If, however, the name 'Narcondam' has been wrongly applied, the mistake is a very old one, dating back at least as far as the end of the sixteenth century.

F. R. MALLET.

Government of India Central Printing Office.—No. 18 S. G. S.—24-4-85.—400.



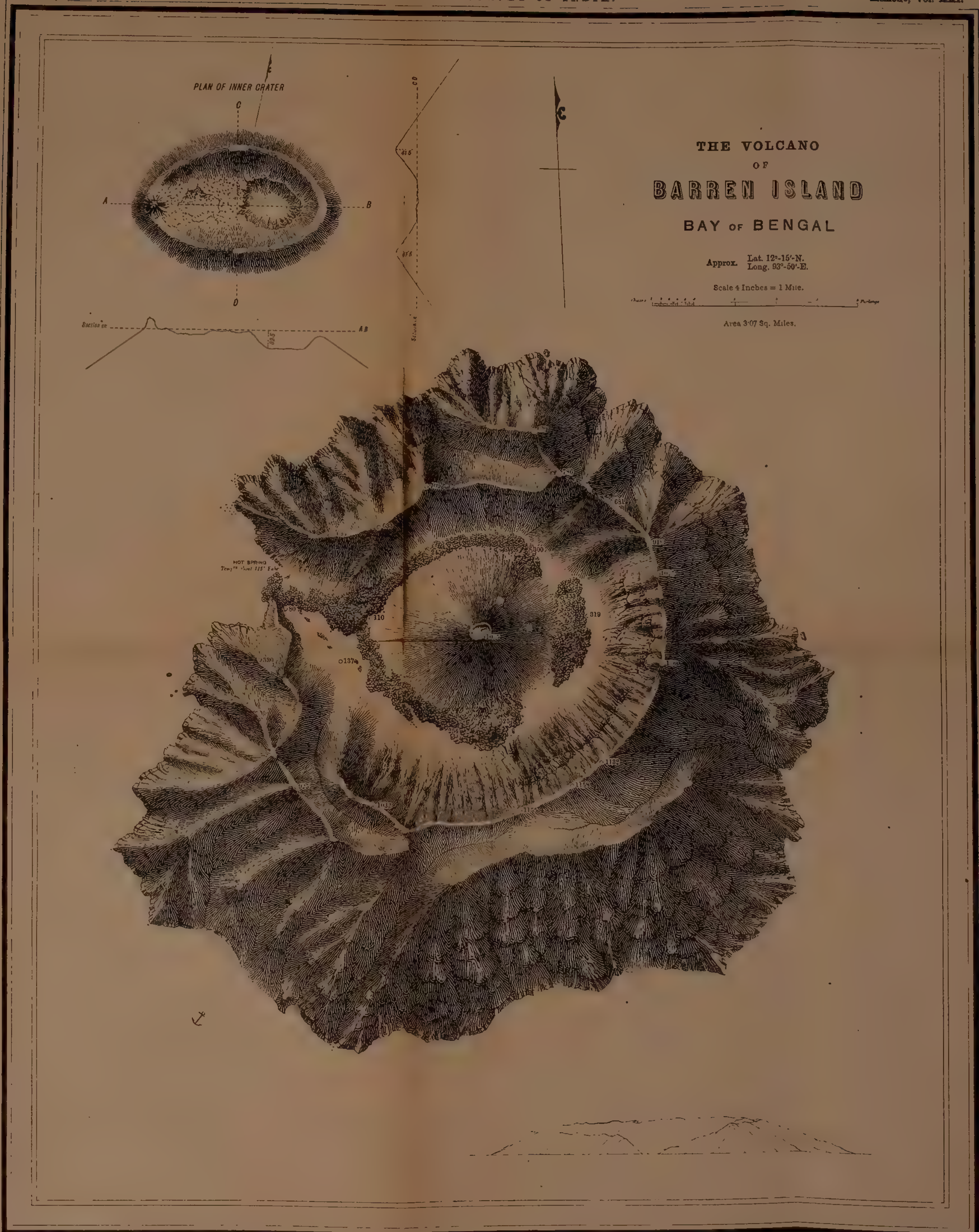
On Stone by Shaikh Khadem Hossain. Printed at Geol: Survey Office.

Surveyed under the direction of Colonel G. C. DePrée, Surveyor General of India, by Captain J. R. Hobday, S.C.

Photozincographed at the Survey of India Offices, Calcutta, January 1885

Surveyed under the direction of Colonel G. C. DePrée, Surveyor General of India, by Captain J. R. Hobday, S C.

PHOTOZINCOGRAPHED AT THE SURVEY OF INDIA OFFICES, CALCUTTA, JANUARY 1888.



Surveyed under the direction of Colonel G. C. DePrée, Surveyor General of India, by Captain J. R. Hobday, S.C.

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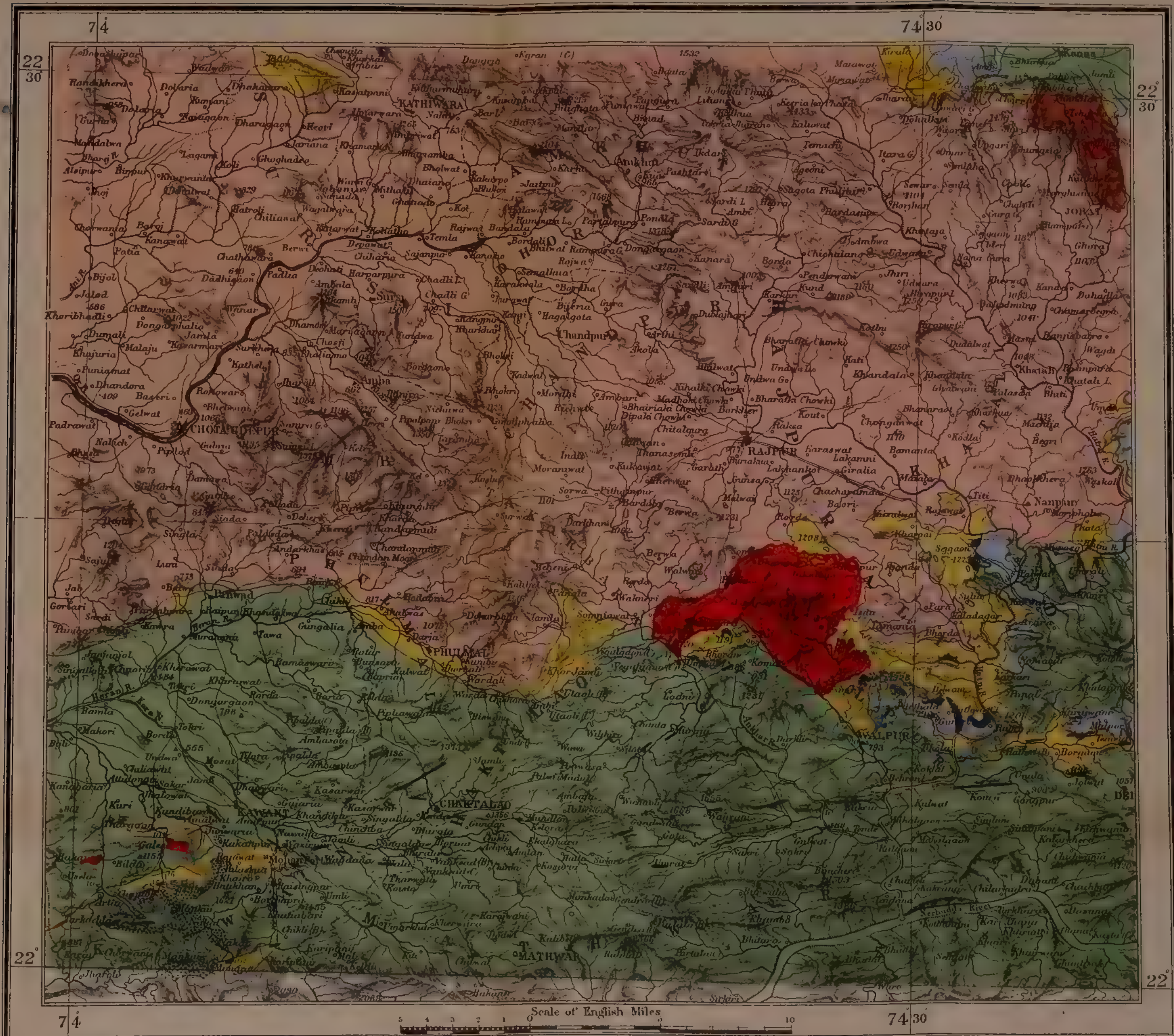


Deccan Trap: Trachytic. Aglomerate. Lameta. Coralline Limestone. Nodular ,, Nimar Sandstone. Upper Vindhyan. Granitic. Gneissic.

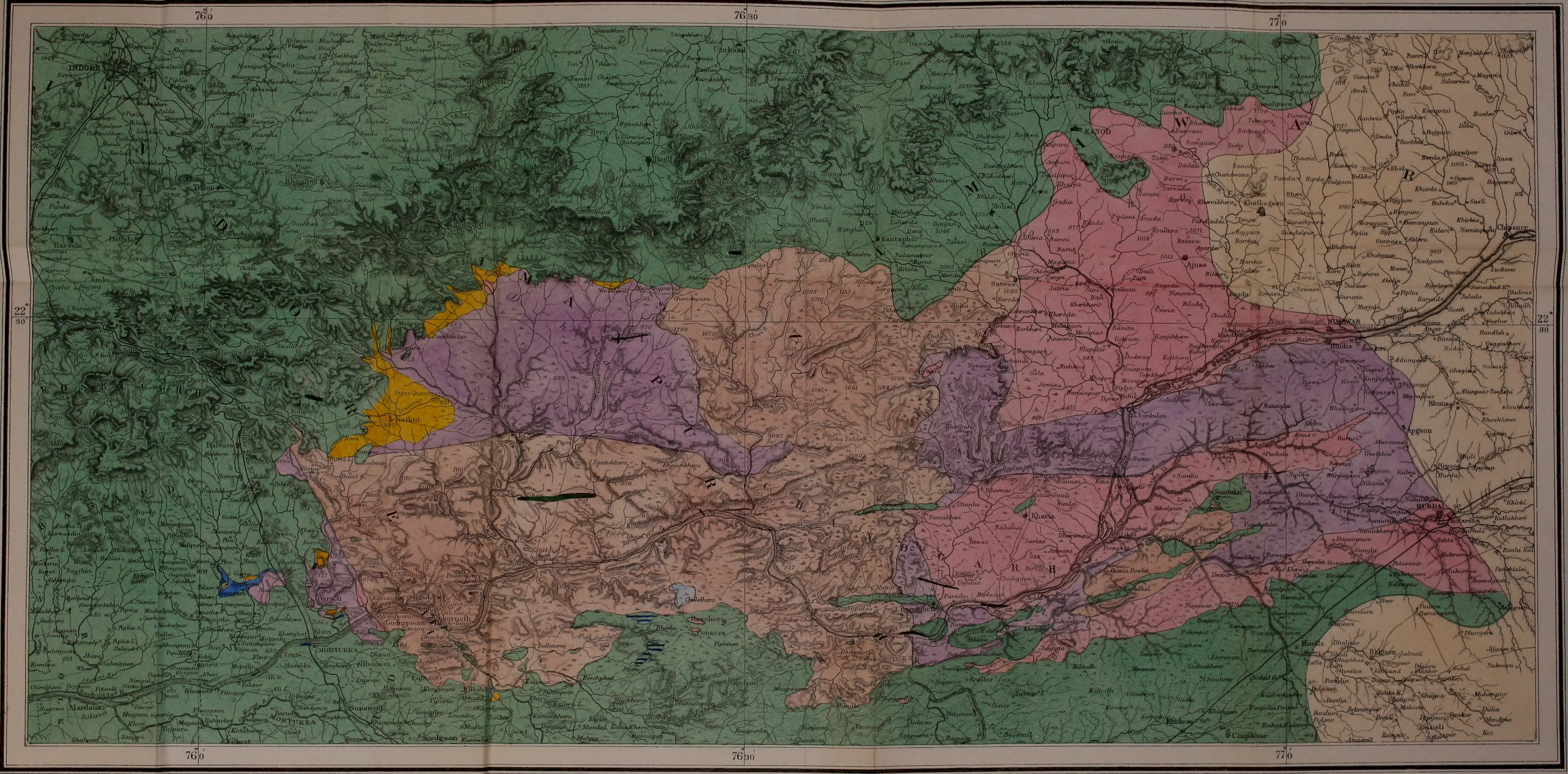
Taken from Sheets Nos. 36 S.E. and 37 N.E. of the Atlas of India.

Deccan Trap: intertrappean; trachytic. — Lameta. — Coralline limestone, Nodular „ — Nimar Sandstone — Upper Vindhyan — Bijawar — Gneissic.

Printed from a transfer to stone in the Litho. Office of the Survey of India Department, Calcutta, March 1884.

Scale 1 Inch = 4 Miles.

5 4 3 2 1 0 5 10 Miles



Taken from Sheets Nos. 53 S.W., 53 S.E., and 54 of the Atlas of India.

Alluvium (boundary arbitrary) | Deccan Trap: intertrappean | Lameta | Coralline limestone, Nodular „, Nimar Sandstone | Upper Gondwana | Upper Vindhyan | Bijáwar | Gneissic.

Printed from a transfer to stone in the Litho. Office of the Survey of India Department, Calcutta, March 1884.

Scale 1 Inch = 4 Miles.

5 4 3 2 1 0 5 10 Miles